University of Aveiro
2014
Department of Civil Engineering

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PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

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The dissertation thesis submitted to the University of Aveiro, to fulfill the requirements for the degree Master in Civil Engineering, conducted under the scientific guidance of Professor Dr. Romeu Vicente da Silva, Assistant Professor, Department of Civil Engineering, University of Aveiro and Polish Supervisor Ph. D. (Dr. Hab.) Dariusz Heim, Assistant Professor, Department of Civil Engineering, Lodz University of Technology.

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Thanks

I would like to express my special appreciation and thanks to my supervisor Professor Romeu Vicente for his immense knowledge, precious time and countless number of helpful advices.

Keywords: Passive building, PHPP, heating demand, PassivHaus, low energy consumption.

Abstract:

This dissertation is part of the final examination for Master of Science in Civil Engineering. Its main objective is to design a house for Polish climate, which will meet all the necessary requirements to achieve the Passive house standard.

At first, the theoretical part of the thesis has been studied. It contains the general Passive house concept, description of energy efficiency requirements, construction solutions, systems and components applied in designed passive building. Also the results for the calculation of linear thermal bridges in THERM can be found in this part of the work.

Following, the practical part of the work has been carried out. Firstly, calculation with the use of Passive House Planning Package (PHPP) for the residential house located in Polish Climate were performed. Secondly, energy calculations for the standard building with the use of PHPP Software and the European Standard EN 1370 have been compared.

To finalize, the results and conclusions of the above-mentioned issues are presented.

Palavras-chave:

Construção passiva, PHPP, Necessidade de Aquecimento, PassivHaus, Baixo Consumo Energético.

Resumo:

O objectivo principal desta dissertação é conceber uma casa adequada ao clima Polaco, que cumpra todos os requisitos do conceito Passive House.

São apresentados e discutidos os princípios teóricos do conceito de Passive House, a descrição dos requisitos de eficiência energética, soluções construtivas, sistemas ativos e components aplicados na concepção de edifícios passivos. Foram efetuados todos os cálculos de pontes térmicas lineares recorrendo ao software THERM.

Foi executado o balance térmico recorrendo ao Passive House Planning Package (PHPP) para uma habitação unifamiliar tipologicamente representativa, localizada na Polónia. Foram ainda realizados o cálculo térmico para um edifício padrão com autilização de PHPP e a norma europeia EN 13790, tendo sido comparados e discutidos.

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Chapter 1

Introduction

1. Introduction

1.1. Background

In recent years, an increasingly popular topic concerning the construction industry becomes energy-efficient buildings. We can say, that their the newest generation are Passive Houses, for which the heat demand is reduced to a greater extent. The growing demand for energy with a simultaneous increase of energy prices means that the energy saving is becoming more widespread and popular. People are starting to pay more attention to subject of saving, looking for solutions that will reduce the cost of living and in the same improving its standards. Also much more in recent time we can hear about environmental protection. We build more and more, which has an adverse impact on the environment that surrounds us. Therefore nowadays, during building a new house we have to take into account the restrictions relating to the protection of the environment, as for example carbon dioxide emission. In many European countries, including Poland are taken actions to rationalize the use of energy and implementation new, high-efficiency technologies. Therefore, to reduce the load on the environment we are looking for new technological solutions that will allow nowadays constructions to be ecological, cheap in the future exploitation and in the same ensure a high quality of life. These requirements are fulfilled precisely by passive buildings, which I think, in the coming years quickly gain in popularity, and because of its many advantages will become the twenty-first century buildings.

1.2. Purpose

The main purpose of choose Passive Houses, as a subject of my thesis is to improve knowledge related to this topic. Passive houses, due to its many advantages are becoming increasingly popular, and I think that in the near future will replace traditional houses. Thus, such knowledge will be very useful in my engineer profession in designing these types of buildings.

1.3. Objective

The objective of my thesis is to design the passive house in Polish climatic conditions, to meet the all the criteria required for this type of objects. Designed construction is a single-family house, 2-storey, without a basement, located in Poznan - city situated in the second polish climatic zone. Architecture of the building, selection of appropriate materials, applied installations and all technological solutions are adapted to the requirements for the passive house.

Chapter 2

What is a Passive House?

2. What is a Passive House?

2.1. Definition of passive house

Dr. Wolfganga Feist – the founder of the Passive House Institute in Darmstadt define passive house as *“A building with a very low energy demand for heating the interior of 15 kWh / (m^2•year), in which thermal comfort is ensured by passive heat sources (residents, electrical appliances, solar heat, waste heat from the ventilation), so that the building does not need a separate active heating system. Heating needs are provided by heat recovery and reheating the air ventilating the building.”* [1]

The more functional and current definition say that *“a passive house is a building in which thermal comfort [EN ISO 7730] can be guaranteed by post-heating or post-cooling the fresh-air mass flow required for a good indoor air quality [DIN 1946]” (Feist, 2007)*[2]

According to dipl. ing. Günter Schlagowski - expert for complex and global solutions in passive construction *“Passive buildings are not only the highest energy efficiency. This is the highest quality and thermal comfort.”*

In the simple way we can say that passive house is a standard of buildings, that provides very good insulating properties and the use of a series of solutions designed to minimize energy consumption during the exploitation. [1].

The most important criteria to consider for passive houses are:

1) Very good thermal insulation of external walls,
2) Reduction of thermal bridges,
3) High level of airtightness of the building,
4) Use of Passive House windows and doors with very low heat losses and high heat gains
5) Highly efficient heat recovery from exhaust ventilation air.

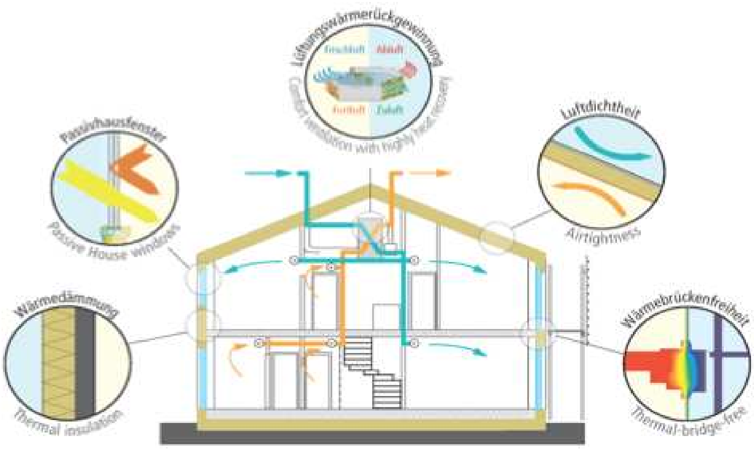


Figure 2.1.1. The five basic principles of passive house. [3]

We use the word “passive” because it doesn’t use any additional active heating system, but it use the energy from different in the “passive” way sources. [1, 4, 5]

That is why passive buildings are the economical solution. When we take into account the monthly costs of investment repayment, operating costs and maintenance building costs as a single monthly charge, it turns out that it is a very profitable investment. Although in the beginning it require more financing for materials and modern technology than it is use in the traditional houses, but we can have guarantee of reimbursement of additional costs, due to the low energy consumption, that which provide us passive construction. [6]

For comparison, the buildings built in Poland in 1966 consume 240-350 kWh /(m^2a) for heating - that is 16-23 times more than passive houses. Newer housing that originated in 1993-1997 have to be heated by the energy of 120-160 kWh /(m^2a), thus 8-10-fold higher. Even the buildings considered to be energy efficient consume 5 times more energy than passive houses. [3] We can clearly see that compare with the traditional building, in the passive building heat losses are dramatically reduced.

According to Prof. Wolfgang Feist from the Passivhaus Institute Darmstadt in the future increasingly popular become the use of renewable energy sources, which will increase the price of energy in comparison with the price of energy produced from fossil fuels at present.

This leads to the conclusion that the increase in energy prices will increase interest in buildings with low energy consumption, which significantly will gain in popularity. [7]

Should also be noted that the idea of passive house is not in any way restricted or protected by law, so it may be used by anyone interested this type of building. It is a generally accessible type of construction and in this standard it is now possible to realize almost any object, both newly and modernized, so for example: single and multifamily residential, offices, hotels, schools, sports halls, swimming pools and industrial facilities. In the construction market appears more and more companies that are involved in with this issue. Also the materials used in the construction of this type are common and generally accessible. All this cause passive constructions to be a topic of increasing interest and contributes to increasing the number of low energy demand buildings. [1, 3]

2.2. History of passive house

Passive construction began in Western Europe during the oil crisis in the seventies. The energy crisis has forced the need to save energy, and it resulted in the adoption of policy designed to significantly reduce the energy consumption of the building and initiated the further development of energy-efficient construction. [8]

The growing trend of more and more dynamically passive construction and energy saving was initiated in 1988 by German physicist Wolfgang Feist and Swedish professor Bo Adamson, who, along with the employees of the Institute of Housing and the Environment (Institut für Wohnen und Umwelt) developed the first guidelines for the passive house.

Figure 2.2.1. Left to right: Bo Adamson, Robert Hastings and Wolfgang Feist 1998 / 2. Passive House Conference Duesseldorf. [9]

After the conference in Düsseldorf in May 1988 there were prepared final guidelines for passive construction and funding for the construction of the first passive house was secured (a project financed by Hessische Ministerium für Wirtschaft, Verkehr und Landesentwicklung, to which belongs Darmstadt).

The first passive house was built in Darmstadt, Germany. It was building of four row houses (terraced houses). The use of modern building materials, carefully selected location and new architectural solutions resulted in the creation of house at drastically lower energy consuming than the previously built houses. The demand for energy is 10 kWh/m^2. The first building passive was an innovative solution, from the architectural and constructional point, but unfortunately very expensive. [8]

Figure 2.2.2. View of the North side of the passive house at Darmstadt Kranichstein. [9]

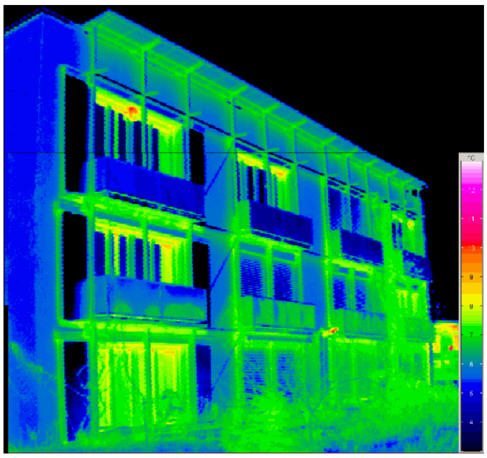


Figure 2.2.3. External thermographic photo of the first Passive House. [9]

In the later period were built more housing estates with passive houses: 21 houses in Wiesbaden, 32 houses in Hanover and 52 houses in Stuttgart. Realizations were accompanied by intensive research programs check whether the design assumptions were confirmed in practice.

In 1998, the idea of passive houses was supported by the European Union through the project CEPHEUS (section of the Thermie program). In Germany, Austria, Sweden and France were created 250 apartments in 14 passive buildings.

In 2003, in Germany, Austria and Switzerland, were more than 3,000 residential housing units in the passive house standard.

In 2005, it is estimated that in the EU countries, there were more than 5,000 housing units based on the passive house technology.

In Poland, the biggest promoter of the idea of passive house construction is the Polish Association for Ecology and Society (KRES), which initiated the project "Passive Buildings - masters of energy saving." [10, 11, 12]

First in Central and Eastern Europe passive building with the necessary certificates of Passive House Institute in Darmstadt was built in 2006 in Smolec, near Wroclaw.

Figure 2.2.4. The first certified passive house in Poland – View. [13]

Figure 2.2.5. The first certified passive house in Poland - Ground floor. [1]

2.3. Criteria for passive house

The criteria for the Passive House standard for houses in Central Europe according to the [PHPP 2007] – [The Passive House Planning Package (PHPP) verification procedure for the energy demand of buildings and a planning tool for Passive Houses] are:

- energy demand necessary to heat the surface of one square meter, in one heating season below 15 kWh / (m^2 • year),
- heat transfer coefficient U for the building envelope (roof, walls, floor on ground) less than 0.15 W / (m^2 •K);
- tightness of the outer shell of the building, checked with the pressure test, during the difference test of internal and external pressure of 50 Pa, times air exchange should not exceed the value of 0.6 h^{-1};
- building envelope made in such way to maximum reduction of thermal bridges;
- window heat transfer coefficient U below 0.8 W / (m2 • K) for the frame and glazing, the total solar energy transmittance for glazing g ≥ 50%;
- efficiency of the recuperator, which is used for heat recovery from ventilation, greater than 75%;
- reduction of heat loss in the preparation and supply of hot water;
- efficient use of electricity. [1, 4]

2.4. Advantages of passive house

According to the Passive House Institute: *“Passive House is a building standard that is truly energy efficient, comfortable and affordable at the same time.”*Although, passive house is a new idea in the approach to energy saving in the modern construction industry, this technology does not cut off from traditional construction, but uses already proven materials and technology. The innovation is based on the use of already existing systems and materials, improving the insulation parameters and air tightness, a reasonable arrangement of windows, rooms inside or outside the plant. [1,15]

For the purposes of passive construction can be adapted practically all types of structures used in conventional buildings. It is therefore possible elevation of objects in wood-frame technology in masonry construction, as well as monolithic reinforced concrete or made of prefabricated elements.

Another advantage is small maintenance costs result from the small energy consumption for heating, domestic hot water and operation of auxiliary equipment. Passive Houses allow for space heating and cooling related energy savings of up to 90% compared with typical building stock and over 75% compared to average new builds. Passive Houses use less than 1.5 l of oil or 1.5 m3 of gas to heat one square meter of living space for a year. [16]

Next aspect is the protection of the environment, namely: less consumption of non-renewable fossil fuels and reduce greenhouse gas emissions, use of renewable sources of energy, such as heat stored in the ground by the ground heat exchanger and the use of environmentally friendly building materials.

To this value affects numerous of parameters, such as, among others: the degree of external walls insulation, the relation of the surface to the volume of the building and the weather conditions prevailing in the place where the building is erected. [17]

What's more, the concept of a passive building naturally connects to the issue of the use of renewable energy sources. Growing, at a frantic pace energy, carriers purchase costs and requirements of the European Union in terms of action against climate change, forcing us to use modern technology, which can make that the future will belong to this particular type of construction. [10,15]

Also passive house provides the high comfort of living. These houses are equipped with mechanical ventilation systems that provide better indoor air quality and lower concentrations of pollutants. Very well insulated walls and windows provide a high temperature, which has a positive impact for thermal comfort. [15, 16]

Efficient ventilation not only provides passive house thermal comfort in winter, but also allows cooling of the incoming air in the summer, allowing for a pleasant interior climate without the need of using dry out the air conditioners. Maintaining uniform temperature of the air in the entire room, including the walls and windows, prevents from air circulation and drafts formation. Moreover, constant exchange of air protects against the development of microorganisms and diseases caused by them. [18]

Passive houses thus provide high comfort of living by creating healthy, friendly environment for users and residents. [17]

At the 8th Passive House Conference, Robert Hastings stated: *“Passive Houses minimize environmental impacts and maximize the joy of life.”*

2.5. Certifications for passive house

To obtain an international Passive House certificate must be met three basic criteria relating to maximum heating or cooling energy, the primary energy demand and maximum air leakage.

The building must be also designed using special software, as is the Passive House Planning Package (PHPP). It have to be made according to the project with exceptional attention to detail. To the most important elements of the construction have to be used products certified by Passive House Institute and during construction and after its completion air tightness tests have to give positive results. [19]

Lack of awareness and knowledge of issues related to energy conservation, including the passive construction causes, on the Polish market, that building energy standard has little influence on its price. The situation of certificated passive houses in Poland compared to Western European countries, describes the President of the Polish Institute of Passive House - Günter Schlagowski: *„In Poland there is a terrible mess, about this issue. There are no formal requirements for energy-efficient construction. In Western European countries are committed to precise the requirements of buildings - the annual heat demand between 40 kWhm^2 and 70 kWhm^2 per year.*

In contrast, here, many people feel betrayed because they have no comparison and possibility to estimate to what extent the building is actually energy efficient. I know the case of Poland, that the energy-efficient building was defined house with two collectors on the roof. Only passive buildings certified by my PIBP Institute or Passivhaus Institute of Darmstadt have met the same parameters across the whole EU. This means the highest level of implementation of all construction stages, from design through construction, leak test to the final certification. In Poland, so far, few objects is thus constructed. For my part, I can assure for this the right tool - PHPP package for the design, optimization, verification, and preparation the object for certification. Only such projects can be certified.“ [20, 15]

In the case of a building, the relevant certificate confirms that it meets the high standards to ensure a high comfort for its users, energy saving, energy efficiency and environmental neutrality. This passive house certification therefore provides a visible form of quality assurance. Another advantage of is the certification is the possibility to apply for financial support for investment offered by banks and public institutions. [21, 22]

2.6. Climatic conditions in Poland

In designing energy-efficient buildings a significant role play local climatic conditions. The importance of the designer grows, because his task is to indicate optimal architectural, structural, material and installation solution for a use of in the specific building. Their individual character results from the specific local climatic conditions and access to renewable energy sources. [23]

According to the standard PN-EN 12831:2006, Poland is divided into five climate zones.

Figure 2.6.1. Polish climatic zones. [24]

Climatic zone	Design outdoor temperature [°C]	The average annual outdoor temperature [°C]
I	-16	7.7
II	-18	7.9
III	-20	7.6
IV	-22	6.9
V	-24	5.5

Table 2.6.1. Design outdoor temperature and average annual outdoor temperature for climatic zones in Poland. [24]

Poland has a temperate climate of a transitional character between maritime and continental climate. This causes the Polish climate is characterized by significant fluctuations during the seasons of the year in consecutive years.

This is particularly true in the winters, which are either wet (oceanic type), or - less often – sunny (continental type).

Generally in northern and western Poland dominate temperate maritime climate with mild, wet winters and cool summers with high precipitation, while the eastern part of the country has distinctly continental climate with harsh winters and hotter, drier summers.

The hottest month is July with the average temperatures of 16-19 °C, while the coldest month in Poland is January. [25]

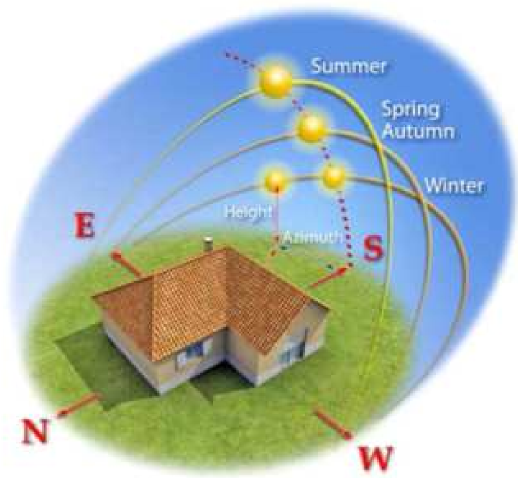


Figure 2.6.2. The different angle of sunlight depending on the season.

Prevailing in the vicinity of Poznan climate conditions are much more unfavourable than climatic conditions in Western Europe, where are built passive buildings. In winter the outside air temperature drops up to - 18 °C. Such low temperatures, usually are accompanied by a relatively large amount of solar radiation, which is characteristic for continental climates. From the point of view of passive houses, that are characterized by a long time constant, much more unfavourable, however, are a few days, cloudy periods with temperatures below - 10 °C and a small amount of solar radiation.

The climatic conditions during the summer whereas not differ from those in Western Europe. The maximum daily temperature is 31.2 °C and an average day 25.34 °C.

In the summer is important to adequate protection against overheating of rooms, because prevails in the room temperature can not exceed the temperature limit of 25 °C for more than 10% of th e hours during the year.

This condition is possible due to different types of solar shading elements both architectural and natural. This condition should be achieved without the use of air conditioning. [26]

Solar energy is available in varying degrees in different countries. Total annual insolation in Poland is relatively large, however, it is characterized by significant non-uniformity of the annual distribution. From the environment point of view, solar energy is the most attractive renewable energy, because using it doesn’t cause any side effects or harmful emissions.

In the summer, the radiation intensity are large and create favourable conditions for the use of solar energy for utility purposes. 80% of the total annual irradiation on a horizontal plane falls to six months in spring and summer, from early April to late September, and only 20% for the period, which corresponds to a heating season. [27]

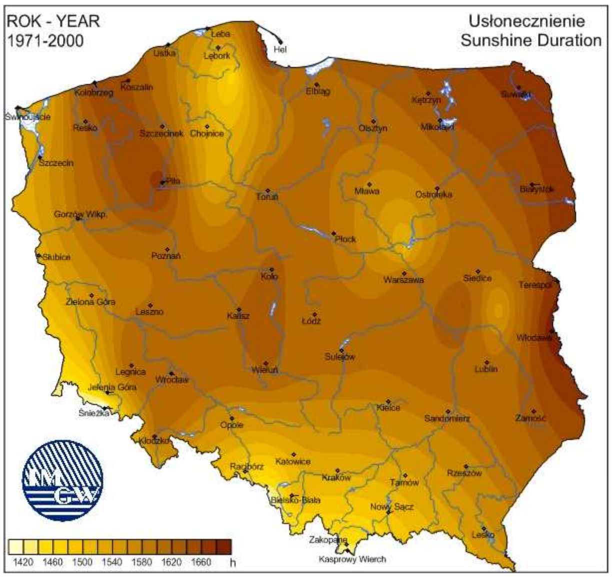


Figure 2.6.3. Average Sunshine Duration in Poland in 1971-2000. [28]

The percentage share of days with cloud cover varies between 60% and 70%. The most cloudy month is November, and the least August and September. Maximum precipitation falls in the summer months. [25]

Significant impact on thermal comfort in passive houses has also wind. Poland is located in zone of prevailing westerly winds (60% of all the windy days). The distribution of winds is not uniform throughout the year.

The summer months are dominated by winds approaching from the west, while in the winter, especially in December and January, their domination is reduced. Typically, on Polish area are weak and moderate winds from 2 to 10 m/s. [25]

2.7. The first certificated passive house in Poland

The first passive house in Poland, which passivity is certified by Passive House Institute in Darmstadt (the creator of the idea of passivity), was built in 2006 in Smolec near Wroclaw. House was executed by the designer, Design Office Lipińscy Houses, as the demonstration object. Developed and applied innovative technology, which was supposed to be as simple and inexpensive to implement. During the construction applied solutions that give a positive final result, namely:

- to eliminate thermal bridges used vertical insulating plinth blocks,
- wall made of leca-concrete prefabricated elements, characterized by good strength even at small sizes (thickness of the outer wall 15 cm),
- used envelope insulation,
- made tight connection of external walls with window woodwork.

At the conclusion made the pressure test, which came out positive. Building achieved the intended tightness. [15]

Figure 2.7.1. A passive house built in Smolec, near Wroclaw. [15]

Figure 2.7.2. Location of the first passive house on the Polish map. [15]

Architecture of Poland's first certified passive house refers to the archetype of single-family house. Simple, compact shape, built on a rectangular plan, with a steep pitched roof fits perfectly in Polish urban landscape. The proportions of the roof and walls were close to those found in traditional buildings. One of the element that enhances body of the building is triangular dormer window on the front elevation with window lightening the bathroom. Maximize the solar heat gains achieved by proper placement of windows on the facades. Large windows on the south facade, in addition to providing energy gains from solar radiation, gave the structure a modern character, enhanced by additional solar collector placed centrally on the roof. On other walls, the size of windows is chosen to provide the required (according to Polish standards) amount of natural light, and at the same time to minimize heat loss. Deliberately abandoned from closure of the northern the facade, because it would lead to a significant deterioration of architecture and reduce the attractiveness of the object. The function solved in a similar way to the traditional, but with innovation elements, imposed even by large glazed surfaces, making the walls of dining room and living room. Home is designed for a family of four and despite the relatively small space it is characterized by a large spaciousness. Additionally glazed south facade causes optical zoom interior. [13]

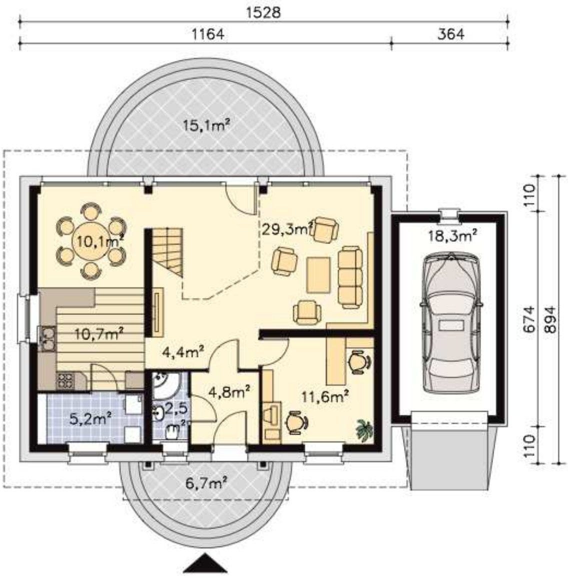


Figure 2.7.3.Ground floor plan of the passive house in Smolec. [15]

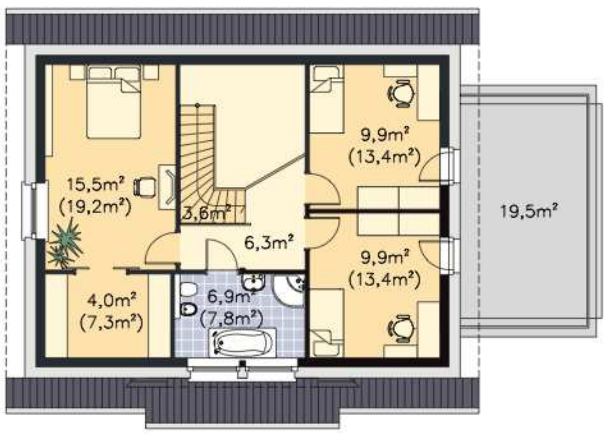


Figure 2.7.4. First floor plan of the passive house in Smolec. [15]

Dr. Eng. ArchLudwika Juchniewicz - Lipińska from the design office of Lipińscy Houses describes the idea of building the first Polish passive house in Poland: *"We focused on the development of a passive house project according to strict guidelines specified by the creator of the passivity idea dr. Wolfgang Feist and at the same time possible to implement in Polish conditions at the lowest possible price. The goal we set ourselves was to built by our project "Lipińscy Passive House 1" the house that deserved to be called a technologically simple and rational. "* [13]

The demand for space heating in passive house in Smolec in standard heating season is 15 kWh/m^2a. The same object built in accordance with existing standards in Poland will use 123 kWh/m^2a, which is over 8 times more. [13]

The number of these objects in Poland is constantly increasing, but is still is still significantly lower than in western countries. One of the reason can be Polish regulations concerning the construction issue. Dipl. ing. Günter Schlagowski consider that they *"Promote the energy consumption instead of more efficient energy consumption."* He also add: *"At one time, an attempt to change undertook construction minister, Andrzej Aumiller. The project identified the need for energy efficient buildings on 50 kWh/m2/y. Following the example of Germany, anticipated to introduce a special, low-interest loan in the amount of 50 thousand zlotys for the object built in passive technology. For the implementation of the Act lacked four months, and so the project after the election went to the trash. The Polish building regulations are still missing a certain standard of building energy-efficient."*

Another reason for the small number of passive houses in Poland with certainty is their high cost of construction. In Poland construction a passive house is 25-30% higher in relation to the construction standard house, and in Germany is only about 5%. [15]

2.8. European Union and national plans

On 5th July 2013, was signed Decree of the Minister of Transport, Construction and Maritime Economy amending the Regulation on technical conditions to be met by buildings and their location (Journal of Laws of 2013, pos. 926). This Regulation shall enter into force on 1 January 2014.

Issued regulation is a consequence of the implementation Article. 4 to 8 of the European Parliament and of the Council 2010/31/EU from 19 May 2010 concerning energy performance of buildings (recast) (OJ EU L 153, 18.06.2010, p 13), referred to "Directive 2010/31/EU. "

Directive of the European Parliament and of the Council 2010/31/EU of 19 May 2010 regarding to energy performance of buildings requires Member States to bring this to the beginning of 2021, that all newly created objects buildings have to be "nearly zero energy ". The new priority program is designed to prepare investors, designers and manufacturers of building materials, contractors to the requirements of the Directive. It will be an impulse for the market to change the way of erecting buildings in Poland and besides the financial benefits for the beneficiaries, will bring significant educational effect for the society. The introduction of discussed Directive aims to economically reasonable improvement of the energy efficiency of buildings as a result of, inter alia, lower heat demand for heating, cooling, domestic hot water and lighting, through the use of, inter alia, appropriate materials (with good thermal insulation parameters), technologies of central heating installation and domestic hot water and assembly techniques with responsible use of some power sources. [29, 30]

Programme will bring benefits to households in the form of:

- Surcharge credit covering the higher part of the investment costs and the costs of building design verification and confirmation for reached energy standard,
- Lower operating costs of the building,
- Increase the value of the building.

This is the first nationwide support instrument for constructing residential buildings with low energy consumption. The budget amounts to 300 million zl. Financial resources will allow for the implementation of about 12 thousand of houses and apartments in multifamily buildings. Implementation of the program is planned for the years 2013-2018, and the disbursement of associated with it funds - for 31/12/2022. [30]

Chapter 3

Energy efficiency requirements for Passive House

3. Energy efficiency requirements

3.1. Passive house windows

The important role in passive house is played by windows. They work as solar collectors: passively acquired solar energy covers heat loss. More important from gaining solar energy, however, is to maintain a low demand for thermal energy. In the light of the requirements for windows by the Passive House Institute in Darmstadt (Feist, 1998), windows for passive houses should be characterized by:

- Overall heat transfer coefficient for a window not higher than 0.8 W/m^2K
- The total heat transfer coefficient for the built window not higher than 0.85 W/m^2K
- Solar radiation transmission coefficient greater than 50%.

Heat loss is the greater, the larger is the window area. For the real passive energy solar gains contributes the use of heat-insulating glazing windows, for example three-glazing windows, filled with argon or krypton, oriented to the south.

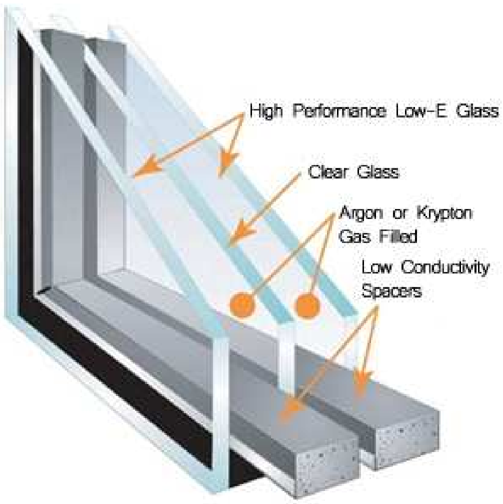


Figure 3.1.1. Elements of Triple Pane Windows.

Due to the need for high quality indoor environment and reduction heat loss through infiltration, windows and doors should be characterized by high thermal insulation. The value of heat transfer coefficient for the whole windows or doors specified in the Technical Approval or counted in accordance with PN-EN ISO 10077-1 should be less than 0.8 W/m^{2}K. To meet this requirement, are used special glazing constructions and frames. Glazed units consist not of two but three panes, and the spaces between them are filled with an inert gas such as argon, xenon. Glass surfaces can be coated with a low-emissivity coating, which improves the thermal insulation properties. They are also used new solutions distance frames, so called warm edge, which reduce heat loss at the connection of the window frame and the glazing. High thermal insulation requirement apply to the frame. Used in passive houses profiles are much broader and insulated with an extra layer of insulation. Appropriate structures are available in both the wood and plastic technology.

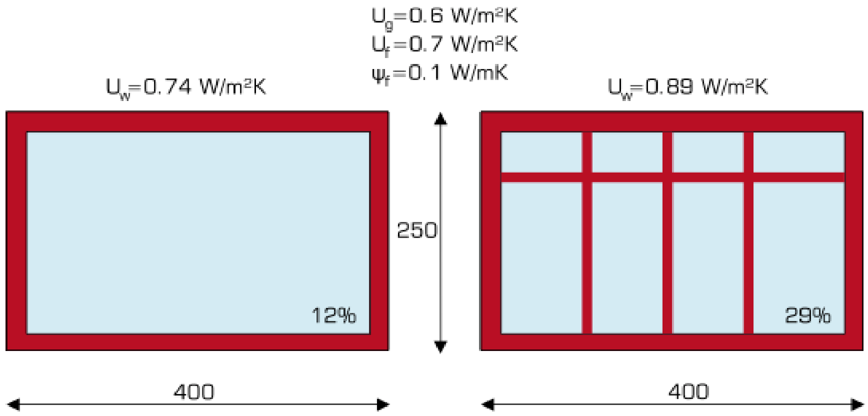
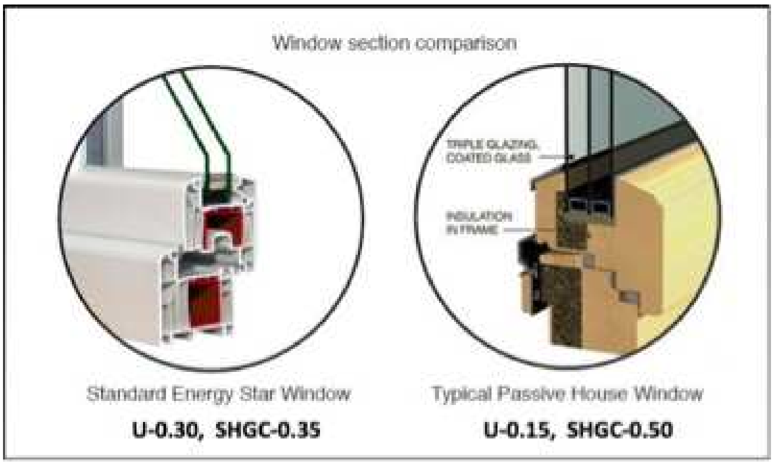


Figure 3.1.2. An example of the impact the share of the frame surface in the total window area on the energy balance. [31]

The task of the large glazed surfaces in passive heating systems is primarily a solar energy profit. However, since the same surface in periods without sun causing great loss of heat, it is necessary to use shields to prevent heat from escaping. These covers can take many forms, such as shutters, blinds, screens and curtains made of different materials, mainly wood, textiles and plastics.

Depending on the type of material and type - the cover can be opened and closed, folding, lowered and raised manually or mechanically. The use of for example blinds can lead to a reduction of the thermal conductivity of windows with 15% for non-insulated profiles and up to 30% for insulated profiles. [32]

A very important element is the correct installation of windows and doors. Defectively made connection of external walls with windows and doors can lead to additional heat loss through thermal bridges and worsen the air tightness of the building. In order to prevent this, is used special mounting systems adapted to the needs of passive buildings. The task of the system solutions is first - elimination of the thermal bridges at the connection windows and external walls, and second - ensuring the permanently tight connection. Elimination of the bridge is achieved by installing windows in the insulation layer, on a specially designed for this anchors and execution of jamb from external insulation raided on the window frame. [15]



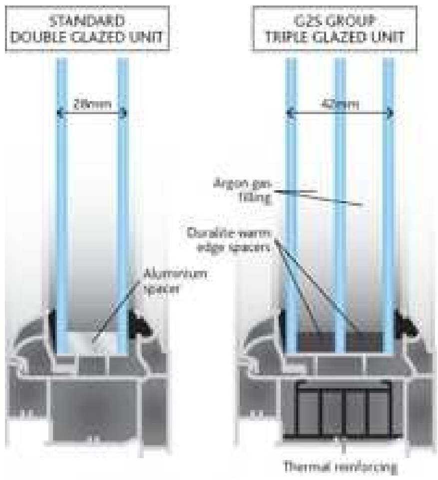


Figure 3.1.3. Comparison of standard Energy Star Window And typical Passive House window. [33]

Figure 3.1.4. Comparison of double and triple glazed units [34]

3.2. Thermal insulation

The design of the passive building envelope is subordinate to the need for maximum reduction of heat loss. External walls, floors, ceilings and roofs must be insulated so that the value of heat transfer coefficient does not exceed 0.15 W/m^{2}K. Increasing the thickness of the insulating layer causes reduction of heat losses and increase of the temperature of the inner partition surface. This has an impact for improving the user comfort of the building.

The design envelope must also be free of thermal bridges, so the places where occurred weakening of the insulating layer and therefore increase heat loss. That is why it is especially important to appropriate design and insulate the building elements, in which bridges may occur. Seemingly minor defects, which are often neglected in traditional buildings, are not acceptable in the passive construction, where great importance have details that impact on overall thermal insulation of the house.

It's important for the buildings to have closed defined thermal coating, covering the entire space of thermal comfort, including all the rooms inside the shell. [32, 35]

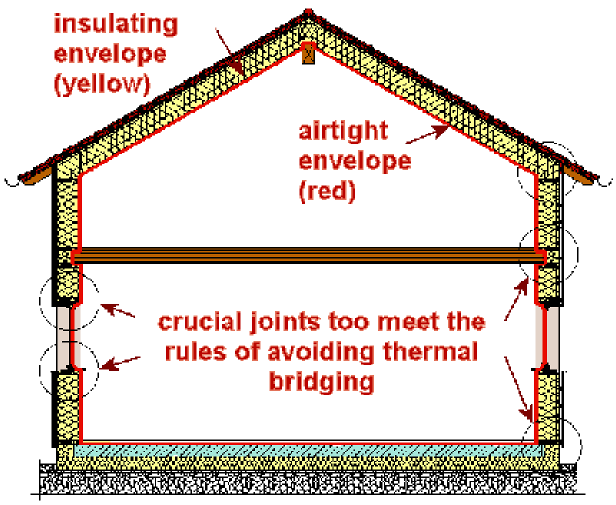


Figure 3.2.1. The scheme showing the main principles for a passive house. [36]

As the amount of solar energy gained by passive building does not always cover the actual heating demand, should be used partitions with a high accumulation of the heat.

Their task is to store heat gains and then release them when the temperature drops inside the building. Heat may be accumulated directly in the, eg. in solid constructions such as walls, or indirectly, e.g. in the stone bed. The direct storage requires the provision of the additional energy, for example to drive the fan, which greatly reduces the effectiveness of this method. Proper use of the heat partitions accumulation allows for mitigation occurring during the daytime, indoor temperature fluctuations. This is better for the comfort of the building and its energy balance. [32]

3.3. Airtightness

One of the basic conditions that must meet the passive house is to provide the so-called airtightness. The airtightness of the building is based on a very precise envelope security against the uncontrolled flow of air through them (convection). It should be noted, however, that the provision of adequate thermal insulation is not synonymous with the fact that the building will be airtight. For example, mineral wool insulation is a good insulating material, but is permeable to air. [38]

By doing coating designed to ensure the tightness of the building, particular attention should be paid to places of all connections such as contact of walls and roof truss, corners, woodwork and other "difficult" points of the building. Everywhere there could potentially be a leak point in the shell. [38]

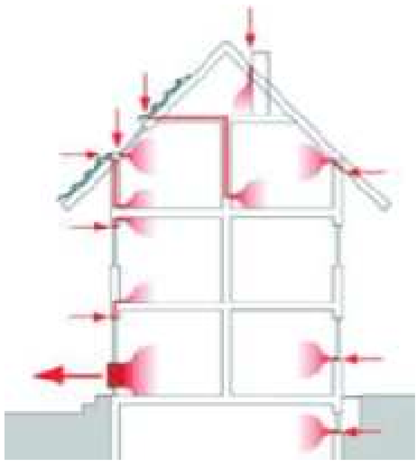


Figure 3.3.1. Location of the most common leaks. [35]

Such weak points in building may just cause condensation of a very large amount of water from the air as a result of the gradual cooling during convection through the barrier. This phenomenon can be very harmful in its consequences, because moisture partition leads to a decrease in its insulating properties, and consequently large energy losses. Moreover, damp partition may be damaged, since it is also susceptible to the formation of mold and mildew. [38]

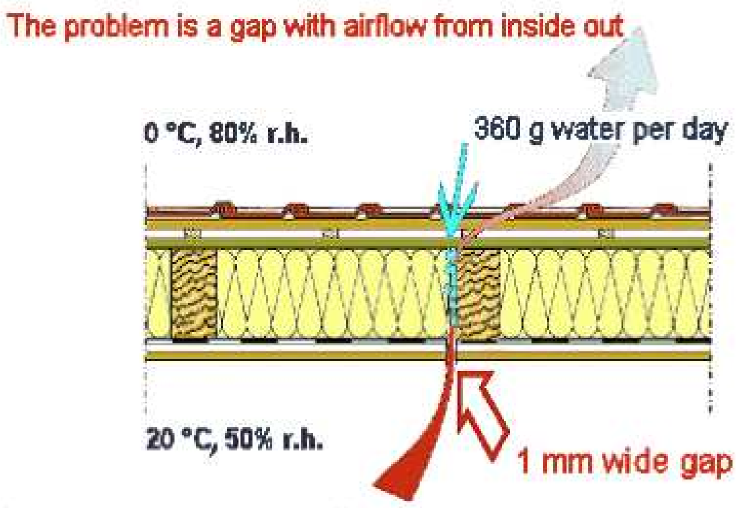


Figure 3.3.2. Not sufficiently airtight construction, where the moist room air can penetrate into the construction, condense and cause damage. [39]

To fully eliminate the formation of leaks in the outer shell of the building, in the construction phase, is carried out the so-called “pressure test”. During this test it is measured parameter n50, specifying the number of air changes in volume of the building within an hour at a pressure difference inside and outside the building at 50 Pa. If the test reveals leaks in the shell, their positions are located manually using a device to measure air velocity (anemometer, thermo anemometer).

Figure 3.3.3. Device to make the pressure test. [40]

Figure 3.3.4. Leak detection using an anemometer. [40]

3.4. Thermal bridges

Thermal bridge is a fragment of the building envelope, that is characterized by significantly worse thermal insulation than the adjacent building elements. Thermal bridges in the walls can increase up to 20% requirement for heat, or increase the cost of home heating. The cause of such places are mostly design and manufacturing mistakes. According to dipl. ing. Günter Schlagowski: *“(…) the ability to avoid thermal bridges is not widely known. Architects must also learn how to properly tightly and without thermal bridges, install windows and doors.”* [15]

Thermal bridges cause large heat loss since they cause cooling building partitions in many points.

These points of thermal bridges are construction nodes, and any connection of external elements made of different materials. Most common places are:

- connections of the floor on the ground with foundation wall,
- connection of the baseplate with an outer wall,
- anchoring seat of windows and doors,
- connection of the roof with a knee wall,
- balcony slabs,
- beams protruding from the outer walls,

- supporting structures such as the mounting location of the steel balustrades, supports, satellite dishes, and even aluminium start-up batten use in light-wet method.

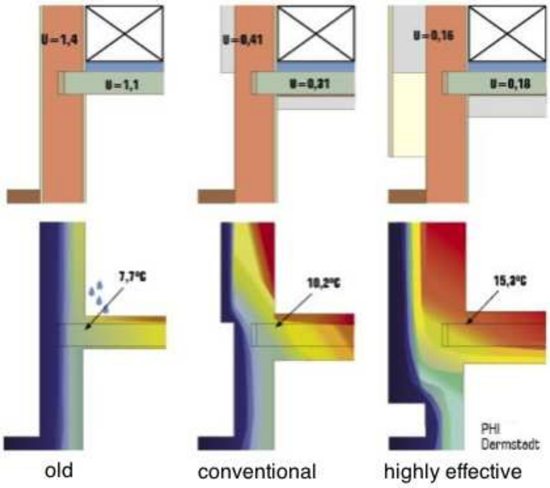


Figure 3.4.1. Thermal bridges at the connection the basement ceiling and the outer wall. [35]

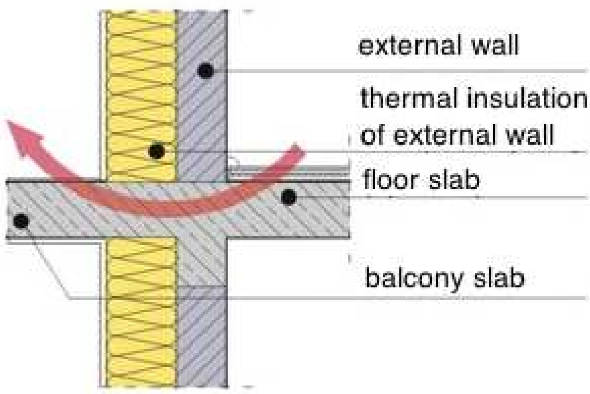


Figure 3.4.2. Scheme showing the escape of heat through the cantilever balcony slab. This solution is often used in conventional buildings. [37]

Avoiding thermal bridges in buildings is therefore essential for proper thermal characteristics of the building. In passive houses, where the priority should be observed as closely as possible the rigor of efficiency should be avoided the use of any solutions that may contribute to the formation of thermal bridges. [37]

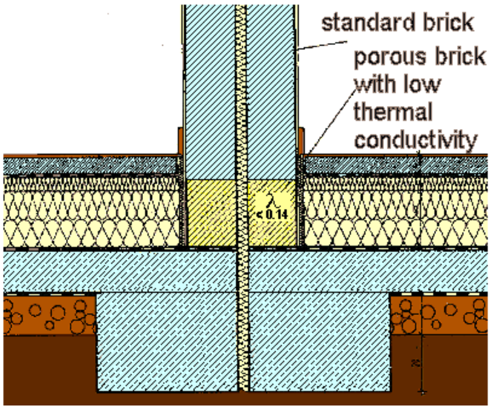
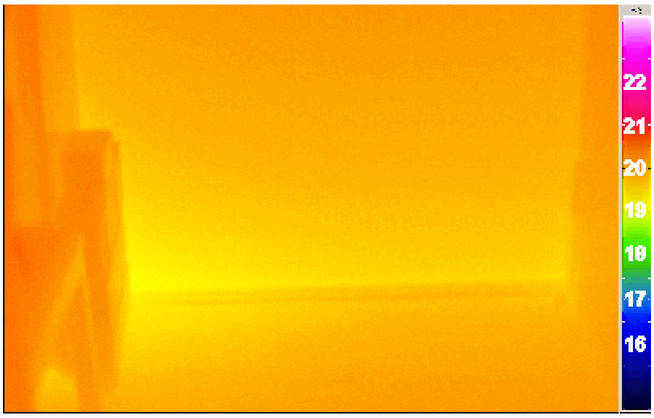


Figure 3.4.3. The thermal bridge at the joint of the interior masonry wall with the slab. [41]



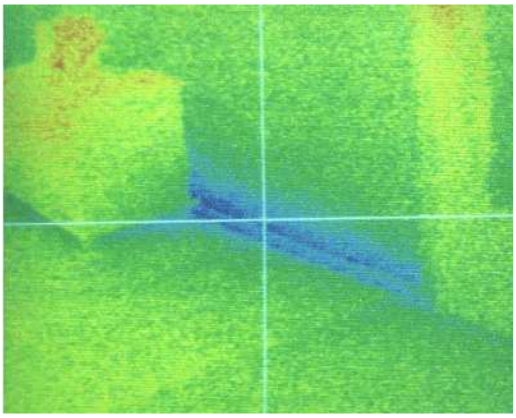


Figure 3.4.4. Infrared picture documenting the thermal separation of the external wall from the concrete basement floor - there is no significant temperature drop. [41]

Figure 3.4.5. Infrared picture documenting situation where is no thermal separation. [41]

3.5. Architectural aspects

A well-designed building must meet a number of very important conditions, often mutually exclusive.

Architect - beside his vision of building - must take into account a number of issues, which include functional requirements, technical, economic, legal, fitting the context of the location, etc. Designing typically requires the cooperation of many people who have influence on the shape of the object. Therefore, the design process is very complicated and requires a lot of knowledge and experience. [42]

Firstly, the shape of the building has to be compact, so that the ratio of capacity to the external partitions surface would provide the least heat loss. [15]

It is also important relative the orientation of the building to the sides of the world. Large areas of glazing should be grouped in the southern elevations, which guarantees that the losses resulting from the heat transfer through the windows will be balanced by profits derived from solar radiation coming through the window. At the facades, differently oriented relative to the the world sides, should as far as possible avoid placing windows. [42]

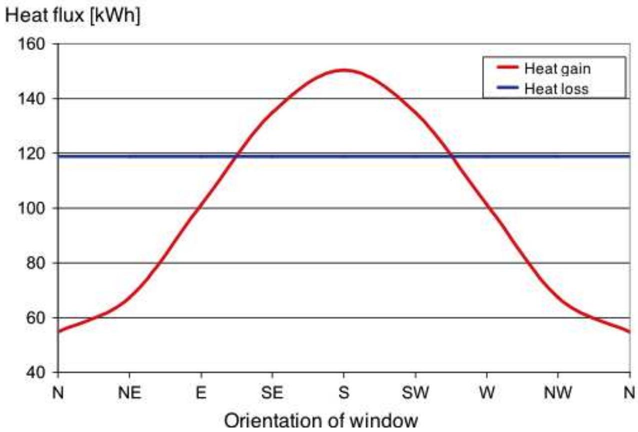


Figure 3.5.1. The energy balance of window in a passive building, depending on its orientation. [41]

It is also essential that large windows should be equipped with different types of awnings or roller blinds, that in the summer season will protect against overheating. This function can also successfully play extended eaves or appropriately shaped balconies. [42]

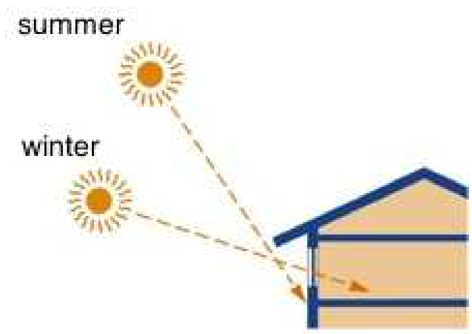


Figure 3.5.2. Eaves - an integral part of solar architecture. [42]

The extended eaves protects window in the summer from sunlight. In the other hand during the winter when the sun is low, beams reach freely into the interior of the building.

Northern wall should not be too much glazed, but it is worth to locate on this side unheated thermally separated rooms, such as a garage or farm building, which will reduce heat loss. Arrangement of the rooms in the building should be such that the rooms of high energy requirements were inside the building (bathroom, toilet), while the north side is better place for example for staircase, where there is no need to dominate the high temperatures. [15]

Very helpful to ensure adequate temperature in the passive building throughout the year can be appropriate design green on the plot. Planting of deciduous trees in front of the southern facade ensures shading in the summer season, when it is important to protect against high temperatures. In the winter, when plants lose their leaves, through unshaded windows let sunlight in, which is a significant source of heat in the energy balance of the building. In turn, on the north side of the building is preferable green softwood that forms a buffer zone against the façade, protecting it in this way from cold winds that may cool down the building. [42]

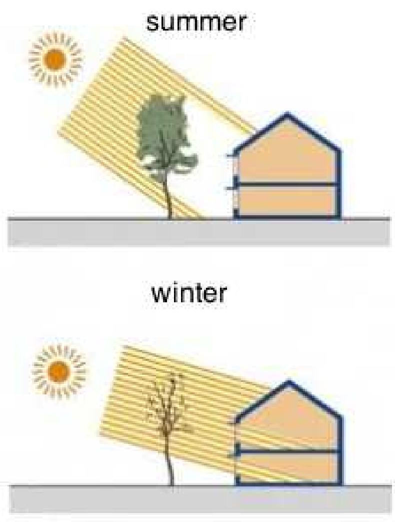


Figure 3.5.3. Scheme of the use deciduous trees to shade the building in summer. [42]

It is important to already at the design stage take into account all of these recommendations. However, there is nothing in the way of using them to create a very modern object or firmly embedded in the tradition, depending on the context of the architectural and urban design, function and concept of the architect and investor expectations. For versatility the idea of passive construction can speak the fact that until now was created in this convention many buildings with strongly differentiated functions such as schools, kindergartens, sports, administrative and offices facilities, residential single and multi-family houses. [42]

Chapter 4

Installations in Passive House

4. Installations in Passive House

4.1. Heating systems

With low heat demand passive building does not have to be equipped with a conventional heating system. To maintain a comfortable indoor temperature, even during the cold winter, should be enough only heating the fresh supply air to rooms by mechanical ventilation. The heat for heating supply air can come from domestic hot water heating system, where the peak load is several times higher. The source of heat can also be connected systems using condensing boiler and heat pump supported by solar collectors used simultaneously for heating, domestic hot water production and ventilation. Ventilation systems in passive houses are characterized by high efficiencies and quality. This is necessary due to the very high energy requirements. In addition, the criterion to reduce the total primary energy consumption by building forces to use solutions with low power consumption. Especially for passive houses there are offered compact central heating, which in one housing hidden all the necessary heating and ventilation installations. The use of popular in recent years, fireplaces and stoves for wood or biomass, raises operational problems in passive houses. Devices typically have a very high heating power of about 2 ÷ 10 kW, resulting in a risk of overheating in a well-insulated building passive.

Air supply to a closed combustion chamber must be done by an external air duct and evacuation of the flue gases through the chimney system (recommended external chimney). Passage of both channels through the shell of the building is a place of potential leaks and thermal bridges. Channels must be very well insulated, which reduces the usable area of housing. It is advisable to use devices that allow the transmission of the greater part of the heat (up to 80%) to the for domestic heat water heating.

The basic criteria determining the choice of additional heat sources are:

- primary energy consumption,
- energy costs in the local market (due to the very small heat consumption, much more importance has the amount of fixed charges)
- additional investment costs of the heat source (e.g. chimney),
- limitations associated with the need to conduct additional installations (air supply, evacuation of the fumes, plumbing, internal insulation of chimney, etc.),
- exploitation (e.g. providing fuel to the boiler, cleaning).

Fulfilling one of the basic criteria - the heating load of 10 W/m^2, allows the use of a common system of air as ventilation and heating system. [15]

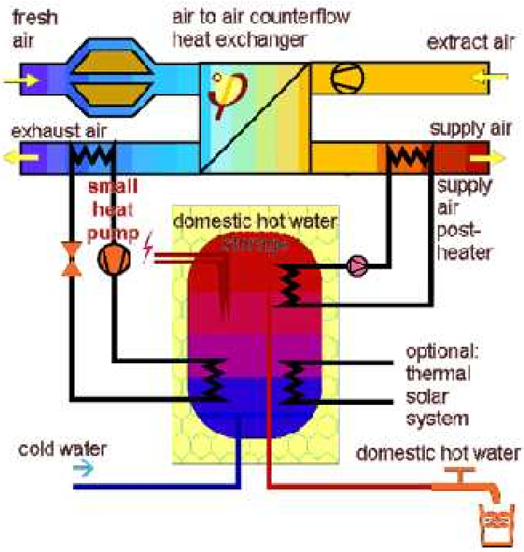


Figure 4.1.1. Compact unit: heating, ventilation and domestic hot water contained in one appliance. [43]

4.2. Ventilation with heat recovery

The ventilation heat losses have a large share in the energy balance of buildings. To achieve the required passive standard is necessary to limit it. For this purpose, is used the mechanical supply-exhaust ventilation with heat recovery instead of natural ventilation. Mechanical ventilation not only helps to reduce heat loss, but also ensures a constant air exchange in the building. [15]

For proper operation of ventilation, it is necessary to provide, air flow through all zones. Due to the comfort of the users should be taken the appropriate order of the rooms ventilation, which takes into account the needs of residents, processes and activities that are carried out in different types of rooms. [44]

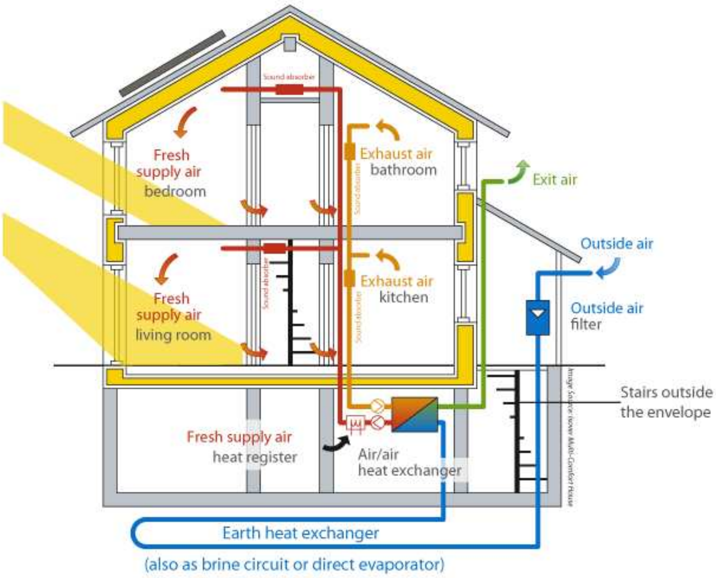


Figure 4.2.2. The scheme of a comfortable ventilation system. [45]

The heart of this system is the air-handling unit equipped with a heat exchanger. The principle of device operation is based on the parallel fresh and waste air streams, passing in opposite directions, in such a way that occurs an exchange of heat between them, without mixing the streams. [44]

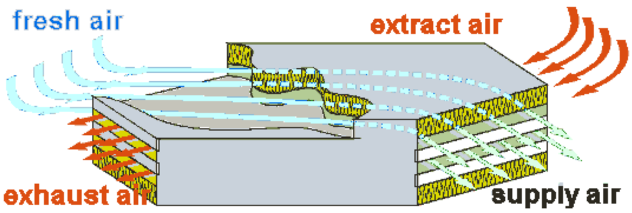


Figure 4.2.3. Scheme of heat exchanger work. [46]

The efficiency of such a device reaches up even to 95%. And the volume of heat loss for ventilation depends not only from the heat recovery efficiency, but also from the degree of airtightness.

The tightness of the outer shell is verified using a special test - Blower Door 4. It is a device with a fan, positioned at the front door or window. It pumps the air from the interior until obtaining a vacuum of 50 Pa. Then is measured the air flow flowing through the leaks. This stream is in a passive house can not be larger than 0.6 exchange of inner, ventilated cubature per hour. By making the vacuum inside the building, can be easily detect and locate any leak, because the incoming air flow can be felt even after by the applying a hand. Using this specialized test we are able to check the services quality of of the executive company.

The test is performed in two series: the vacuum and the overpressure, and the tightness of the building is determined basis of the average results of the two series. The end result of the study is to determine the value of n50.
Increasing the effectiveness of the ventilation system can be achieved by using ground heat exchanger (GHE). Mostly the ground heat exchangers is a plastic or ceramic pipe placed in the ground below the frost line. GHE is used for preheating ventilation air (from warmer than the ground outside air) supplied to the recuperator in the winter and cooling it in summer. [15]

4.3. Domestic hot water (DHW)

For DHW heating in passive houses are often used solar systems, heat pumps using waste heat from the ventilation system or waste water. In the energy balance of a passive building, an energy demand for hot water is a big part, which is why special attention is paid to reducing heat loss in the domestic hot water system. The savings are achieved by proper insulation of the hot water supply pipe. Heat loss can also be partially eliminated in the installation of cold water. The cold water flowing into the building has usually a temperature not higher than 10 ℃, then heated in p ipes and other tanks in the building (e.g., the toilet cistern chamber). This causes a loss of energy, so in the passive buildings special attention is paid to limiting the length of the installation of cold water, its good insulation and economical fittings. It is also applied a device using gray water for flushing the toilet bowl and appliances for heat recovery from waste water disposed from the building. [15]

4.4. Electricity consumption

An important parameter characterizing passive buildings is the amount of primary energy consumed per m^2 of usable area within a year. This amount may not exceed 120 kWh/m^2/year. Therefore, in addition to a significant reduction in demand for thermal energy are required actions to reduce electricity consumption. Becomes important to equip the building with energy-saving lighting, home electronics and appliances, elevators and pumps drives, and other devices. Although the need for lighting generally does not exceed 25% of the energy consumed by the building, the opportunities for energy savings in this area are significant, because the use of energy efficient light sources can save up to 80% of the energy used for lighting. [15]

Chapter 5

Case study – construction detailing

5. Case study – construction detailing

5.1. General building description

The subject of this dissertation is the project of the single-family house, designed in accordance with the Passive House standard. This means that the construction of the house has to have the minimum heat losses simultaneous with the highest solar gains. Reducing of the heat losses is ensured by a significant increase in the insulation thickness compared to the standard houses designed in Poland. For the insulation of the walls and floor it was applied Styrofoam with improved insulation properties and a thickness of 30cm.

The designed building has two floors without basement. Clear storey height is 2.5m. It is constructed in the traditional technology with reinforced concrete elements. The supporting structure is constituted by reinforced concrete and masonry with reinforced concrete beams.

The roof is flat with a slope of 3˚, made from the precast beam and block floor TERIVA, characterized by good thermal and acoustic insulation, and light weight.

The design of a passive house is of great importance. To obtain the highest solar gains, large windows were designed on the southern facade of the building, providing in this way plenty of natural light, also providing modern character to the building. On the northern facade, the number of windows and glazing area is extremely limited to ensure the least possible heat losses, especially in the winter.

An important part of the design of such objects is also landscaping. The trees are located on the southern side of the building, allowing for the shading it in the summer, while in the winter when the trees lose their leaves, the sun's rays are free to hit the glazings.

The building has a simple, uncomplicated shape. The facade is finished with the silicate plaster. In order to make the building's elevation more interesting, it was used wooden facade panels.

The building effective surface is 106,1 m^2. The compartments located in the designed house, the usable areas and final covering of each compartment are listed in Table 5.1.1. and Table 5.1.2.

Table 5.1.1. Areas of compartments - ground floor.

AREAS OF COMPARTMENTS			
GROUND FLOOR			
Nr	Name of compartment	Usable area [m^2]	Final covering
01	Vestibule	3.40	Gres tiles
02	WC	2.67	Gres tiles
03	Pantry	2.14	Terracotta tiles
04	Kitchen	8.52	Terracotta tiles
05	Living room + dining room	20,17	Wooden panels
06	Hall 1	8,22	Gres tiles
07	Utility room	5.06	Gres tiles
	Total	51.17	

Table 5.1.2. Areas of compartments - first floor.

AREAS OF COMPARTMENTS			
FIRST FLOOR			
Nr	Name of compartment	Usable area [m^2]	Final covering
11	Hall 2	12.69	Gres tiles
12	Bedroom 1	8.39	Wooden panels
13	Bedroom 2	8.76	Wooden panels
14	Bathroom	9.02	Gres tiles
15	Bedroom 3	12.91	Wooden panels
16	Wardrobe	3.12	Wooden panels
	Total	54.89	

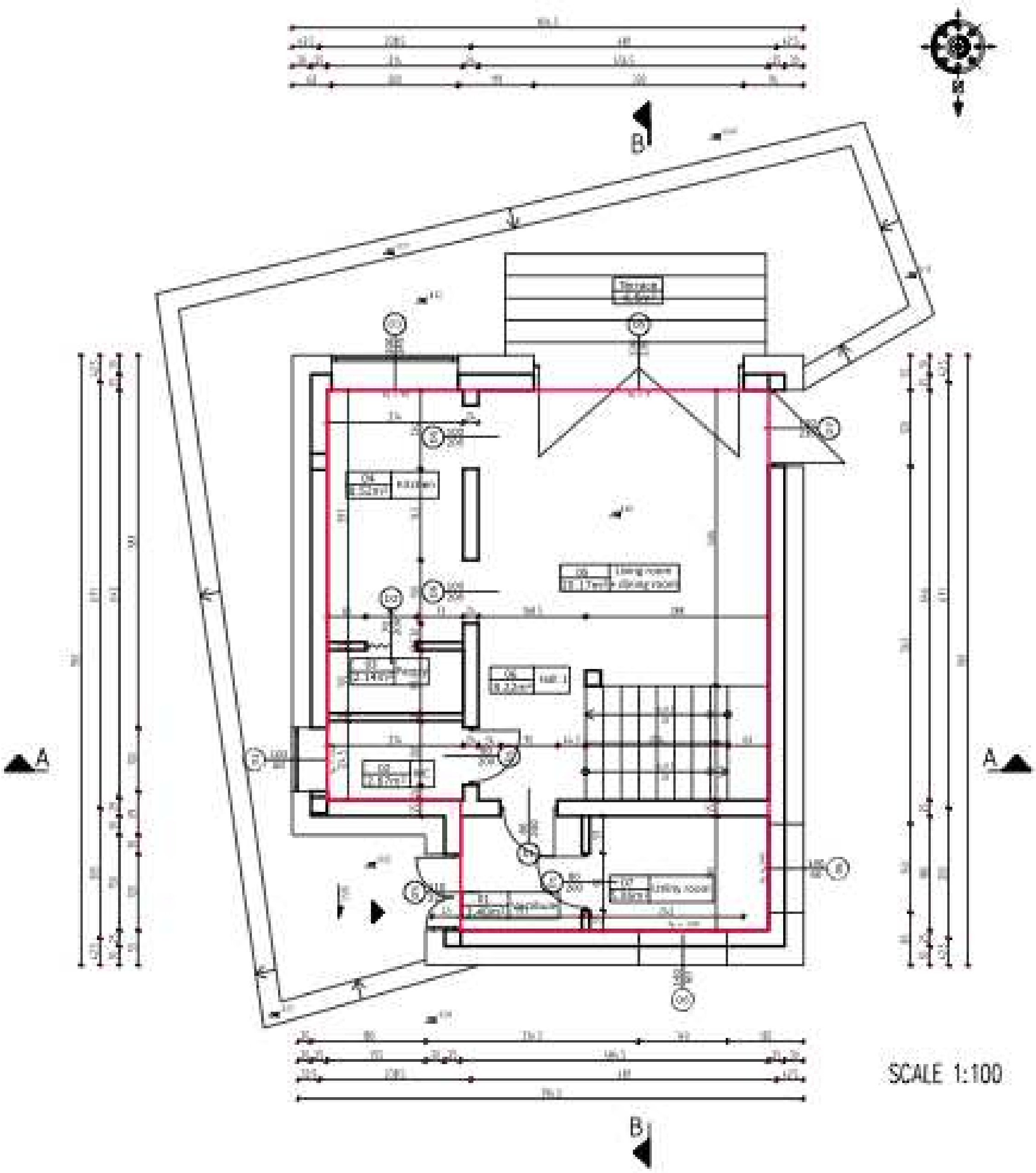


Figure 5.1.1. Ground floor plan.

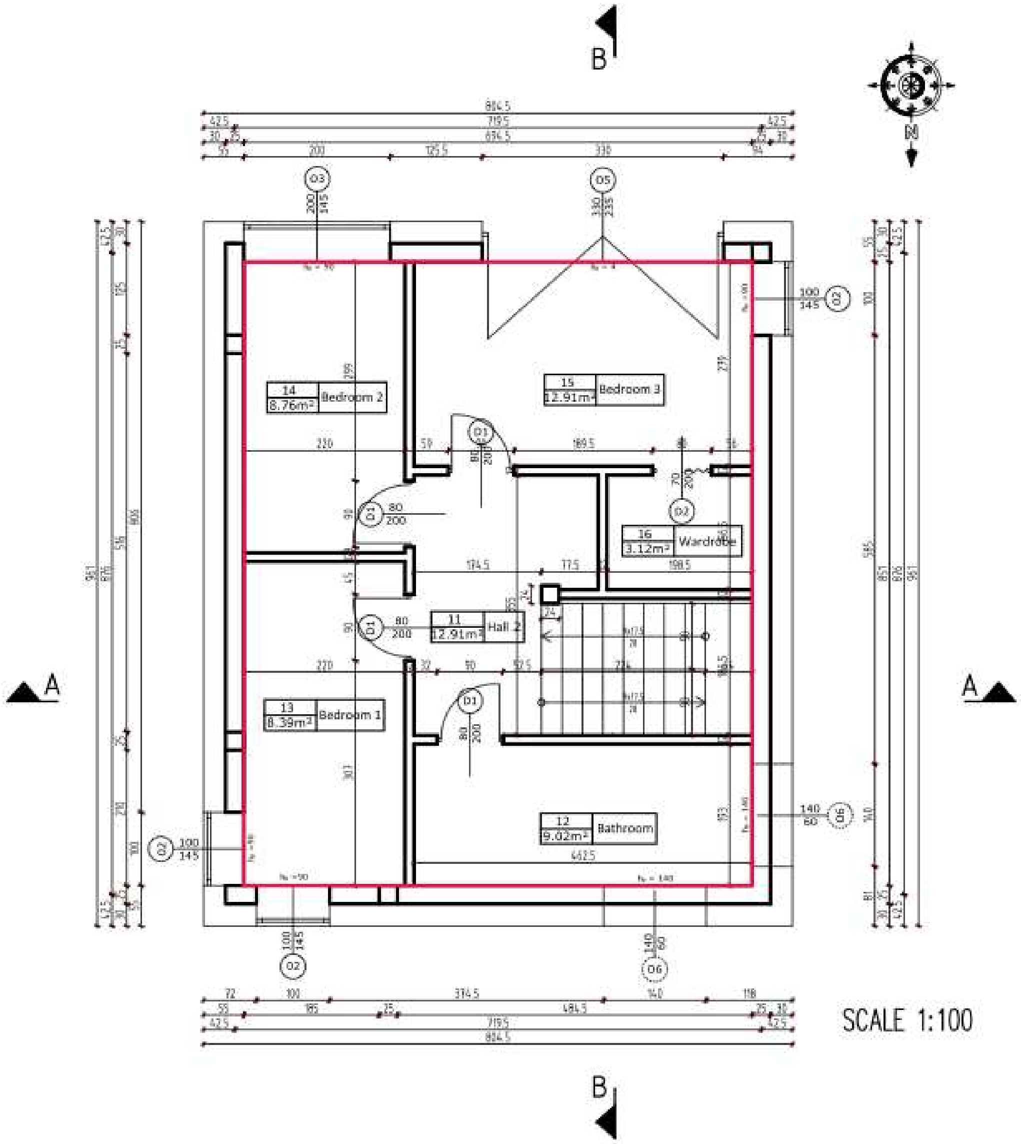


Figure 5.1.2. First floor plan.

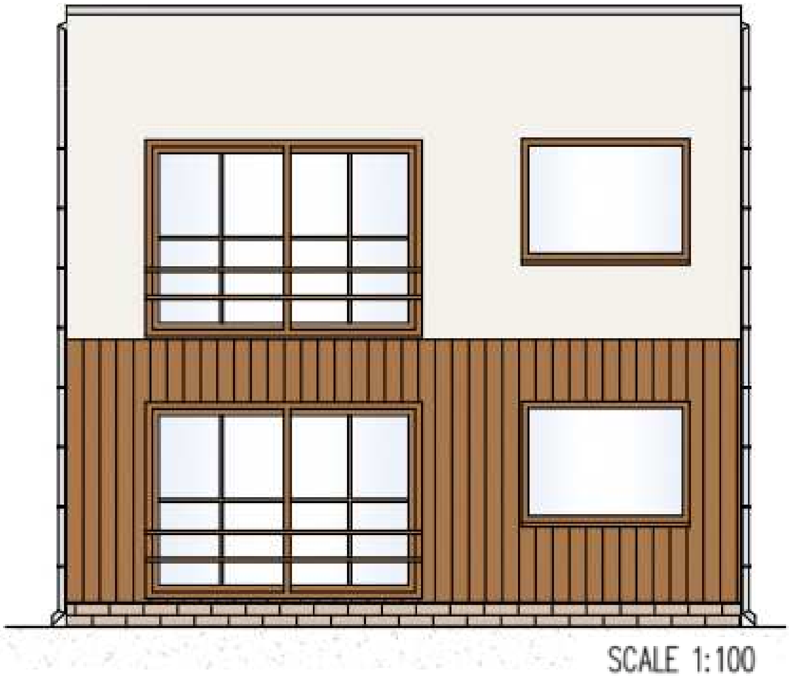


Figure 5.1.3. South elevation.

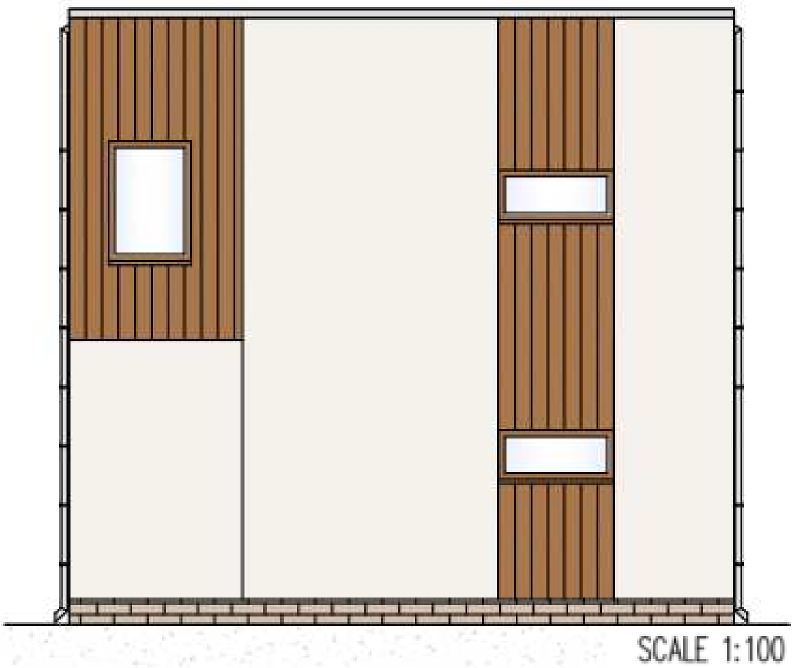


Figure5.1.4. North elevation.

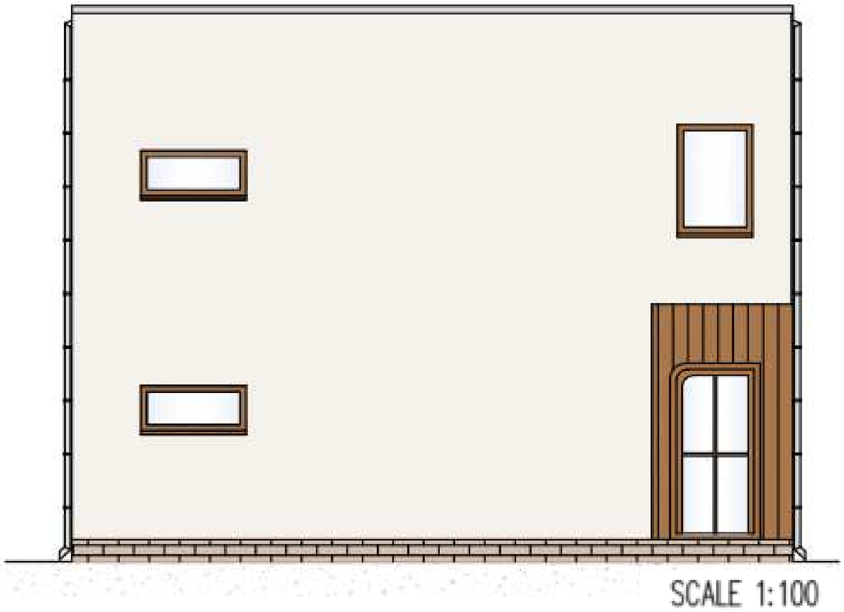


Figure 5.1.5. West elevation.

Figure 5.1.6. East elevation.

Figure 5.1.7. Visualization of the North-East elevations.

Figure 5.1.8. Visualization of the South-West elevations.

5.2. Construction detailing and solutions

5.2.1. Introduction

For the Polish climate, the most important issue during the building design is to reduce the heat losses. Without a high improvement of thermal protection, the realization of standard passive house is impossible. In Poland for the standard house with the average thickness of the insulation, the room with a large south window heats upon a sunny day, but in the night cools down, because the energy too quickly dissipates the room. Therefore, only with good thermal protection the passive use of solar energy will actually be effective. The insulation of the partition must therefore be of the highest quality, as well as in the closed and uninterrupted way, protect around the entire building. The passive standard will be achieved only when the losses will be so reduced that even occurring in Poland in December and January low light, will be enough to maintain the thermal comfort [47].

5.2.2. Exterior walls solutions

To calculate the U-value as accurately as possible, calculations for the external wall were made separately – for the exterior wall covered with plaster and with wooden facade panels.

5.2.2.1. Exterior wall covered with plaster

The structure of the exterior wall is shown in Figure 5.2.2.1.1.

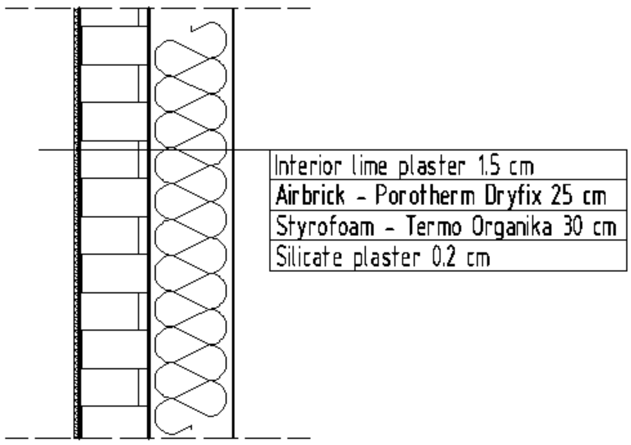
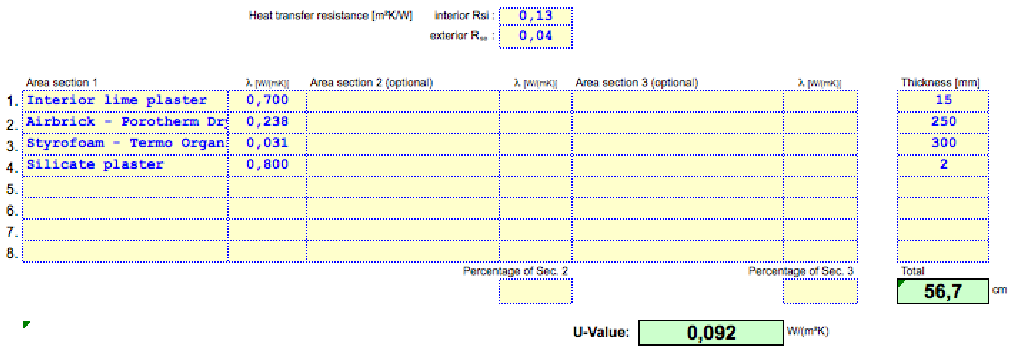


Figure 5.2.2.1.1. Structure of the exterior wall covered with plaster.

The values for the exterior wall covered with plaster were input to PHPP, as shown in Figure 5.2.2.1.2.



Heat transfer resistance [m²K/W] interior Rsi : 0,13; exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Airbrick - Porotherm Dr	0,238					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							

Percentage of Sec. 2; Percentage of Sec. 3; Total 56,7 cm

U-Value: 0,092 W/(m²K)

Figure 5.2.2.1.2. Data from PHPP for the exterior wall covered with plaster.

The obtained U-value for the exterior wall covered with plaster is **0,092 W/(m^{2}K)**.

5.2.2.2. Exterior wall covered with panels

The structure of the exterior wall is shown in Figure 5.2.2.2.1.

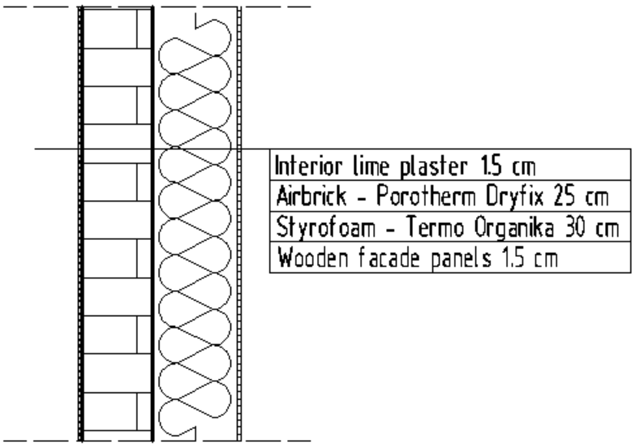


Figure 5.2.2.2.1. Structure of the exterior wall covered with panels.

The values for the exterior wall were input to PHPP, as shown in Figure 5.2.2.2.2.

Heat transfer resistance [m²K/W] interior Rsi : 0,13
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Airbrick - Porotherm Dr	0,238					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
							58,0 cm

U-Value: 0,091 W/(m²K)

Figure 5.2.2.2.2. Data from PHPP for the exterior wall covered with panels.

The obtained U-value for the exterior wall covered with panels is **0,091 W/(m^{2}K)**.

5.2.2.3. Concrete column in exterior wall covered with plaster

The structure of the exterior wall with concrete column is shown in Figure 5.2.2.3.1.

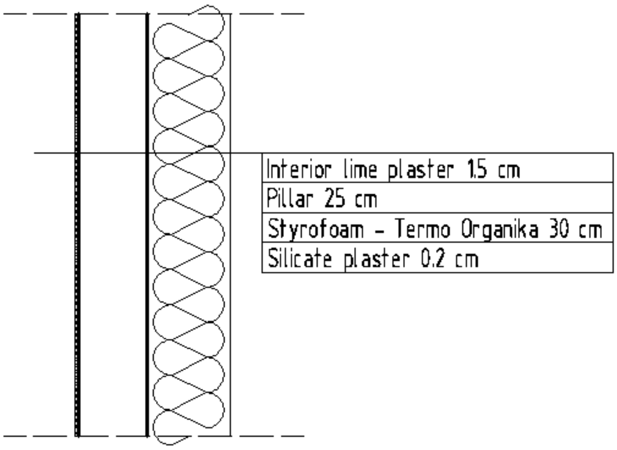


Figure 5.2.2.3.1. Structure of the exterior wall with concrete column covered with plaster.

The values for exterior wall with the concrete column were input to PHPP, as shown in Figure 5.2.2.3.2.

Heat transfer resistance [m²K/W] interior R_{si} : 0,13
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total 56,7 cm

U-Value: 0,100 W/(m²K)

Figure 5.2.2.3.2. Data from PHPP of the exterior wall with concrete column covered with plaster.

The obtained U-value for the exterior wall with the concrete column covered with plaster is **0,091 W/(m^{2}K)**.

5.2.2.4. Concrete column in the exterior wall covered with panels

The structure of the exterior wall with the concrete column is shown in Figure 5.2.2.4.1.

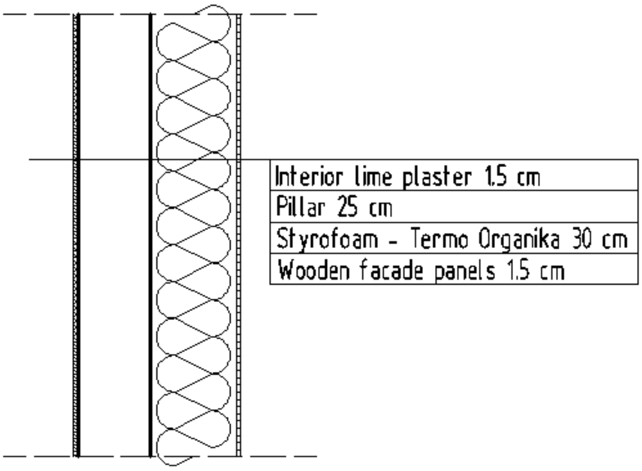


Figure 5.2.2.4.1. Structure of the exterior wall with concrete column covered with panels.

The values for the exterior wall with the concrete column were input to PHPP, as shown in Figure 5.2.2.4.2.

Heat transfer resistance [m²K/W]	
interior Rsi :	0,13
exterior R_{se} :	0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ:	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total 58,0 cm

U-Value: 0,099 W/(m²K)

Figure 5.2.2.4.2. Data from PHPP of the exterior wall with concrete column covered with panels.

The obtained U-value for the exterior wall with the concrete column covered with panels is **0,099 W/(m^{2}K)**.

5.2.2.5. Concrete beam in the exterior wall covered with plaster

The structure of the exterior wall with the concrete beam is shown in Figure 5.2.2.5.1.

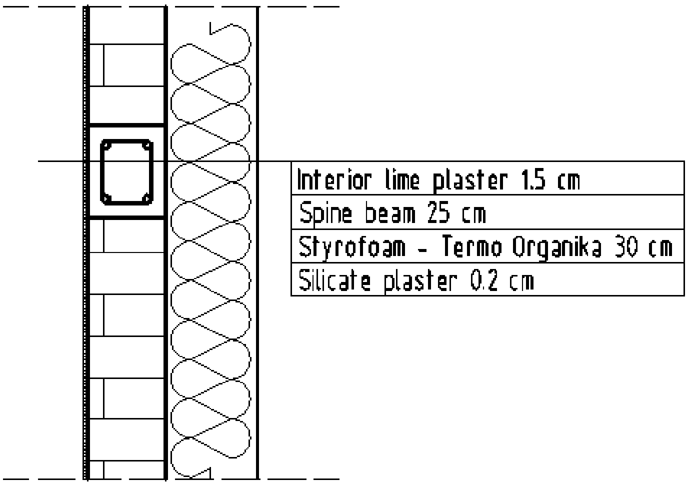


Figure 5.2.2.5.1. Structure of the exterior wall with the concrete beam covered with plaster.

The values for the exterior wall with the concrete beam were input to PHPP, as shown in Figure 5.2.2.5.2.

Heat transfer resistance [m²K/W] interior R_{si} : 0,13
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ:	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total 56,7 cm

U-Value: 0,100 W/(m²K)

Figure 5.2.2.5.2. Data from PHPP for the exterior wall with the concrete beam covered with plaster.

The obtained U-value for the exterior wall with the concrete beam covered with plaster is **0,100 W/(m^{2}K)**.

5.2.2.6. Concrete beam in the exterior wall covered with panels

The structure of the exterior wall with the concrete beam is shown in Figure 5.2.2.6.1.

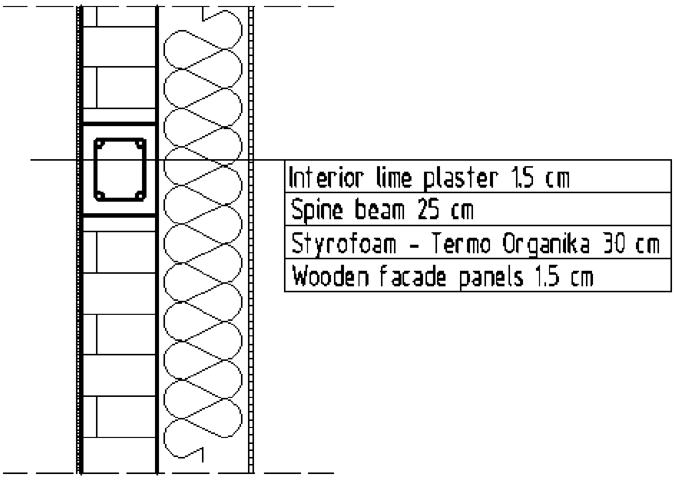


Figure 5.2.2.6.1. Structure of the exterior wall with the concrete beam covered with panels.

The values for exterior wall with the concrete beam were input to PHPP, as shown in Figure 5.2.2.6.2.

Heat transfer resistance [m²K/W] interior Rsi : 0,13
exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total 58,0 cm

U-Value: 0,099 W/(m²K)

Figure 5.2.2.6.2. Data from PHPP for the exterior wall with the concrete beam covered with panels.

The obtained U-value for the exterior wall with the concrete beam covered with panels is **0,099 W/(m^{2}K)**.

5.2.2.7. Window lintel in the exterior wall covered with plaster

The structure of the exterior wall at the window lintel is shown in Figure 5.2.2.7.1.

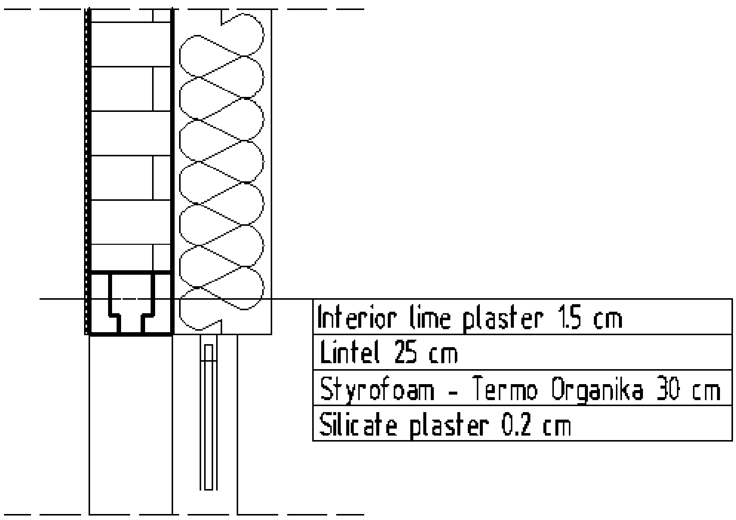


Figure 5.2.2.7.1. Structure of the exterior wall at the window lintel covered with plaster.

The values for the exterior wall at the window lintel were input to PHPP, as shown in Figure 5.2.2.7.2.

Heat transfer resistance [m²K/W]		
	interior Rsi :	0,13
	exterior R_{se} :	0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Concrete	1,300	Reinforced concrete	1,700			250
3.	Styrofoam - Termo Organ	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							
			Percentage of Sec. 2	55,0%	Percentage of Sec. 3		Total 56,7 cm

U-Value: 0,100 W/(m²K)

Figure 5.2.2.7.2. Data from PHPP for the exterior wall with the window lintel covered with plaster.

To calculate the U-value for the lintels made of reinforced concrete were performed calculations to determine percentage of reinforcement in concrete lintel of about 55%.

The obtained U-value for the exterior wall at the window lintel covered with plaster is **0,100 W/(m²K)**.

5.2.2.8. Window lintel in the exterior wall covered with panels

The structure of the exterior wall at the window lintel is shown in Figure 5.2.2.8.1.

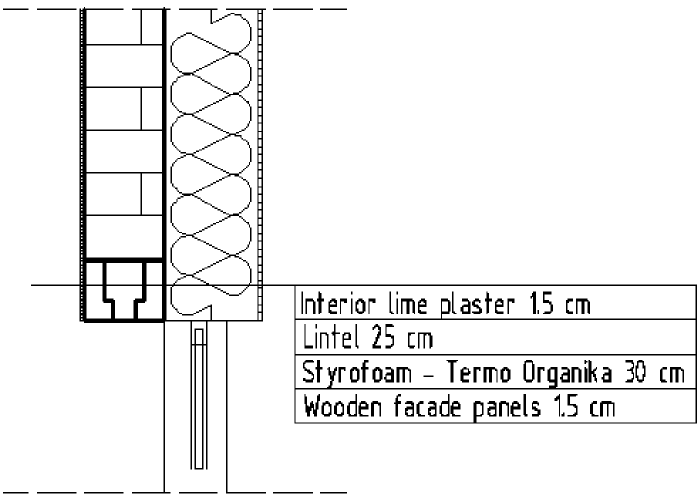


Figure 5.2.2.8.1. Structure of the exterior wall at the window lintel covered with panels.

The values for the exterior wall at the window lintel were input to PHPP, as shown in Figure 5.2.2.8.2.

Heat transfer resistance [m²K/W] interior R_{si} : 0,13
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Concrete	1,300	Reinforced concrete	1,700			250
3.	Styrofoam - Termo Organ	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							
			Percentage of Sec. 2	55,0%	Percentage of Sec. 3		Total 58,0 cm

U-Value: **0,099** W/(m²K)

Figure 5.2.2.8.2. Data from PHPP for the exterior wall with the window lintel covered with panels.

To calculate the U-value for the lintels made of reinforced concrete were performed calculations for determine percentage of reinforcement in concrete lintel of about 55%.

The obtained U-value for the exterior wall at the window lintel covered with panels is **0,099 W/(m^{2}K)**.

5.2.3. Roof solutions

Since the roof structure is not uniform along its entire surface, the U-Value was calculated taking into account the four cross sections through the roof slab, as shown in Figure 5.2.3.1.

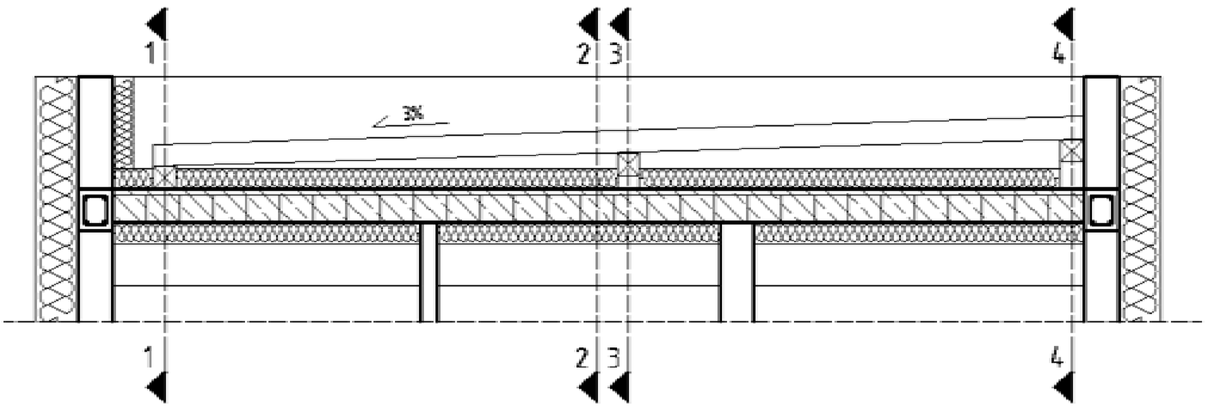


Figure 5.2.3.1. Roof cross sections used in U-Value calculation.

5.2.3.1. Roof – cross section 1-1.

The structure of the roof cross section 1-1 is shown in Figure 5.2.3.1.1.

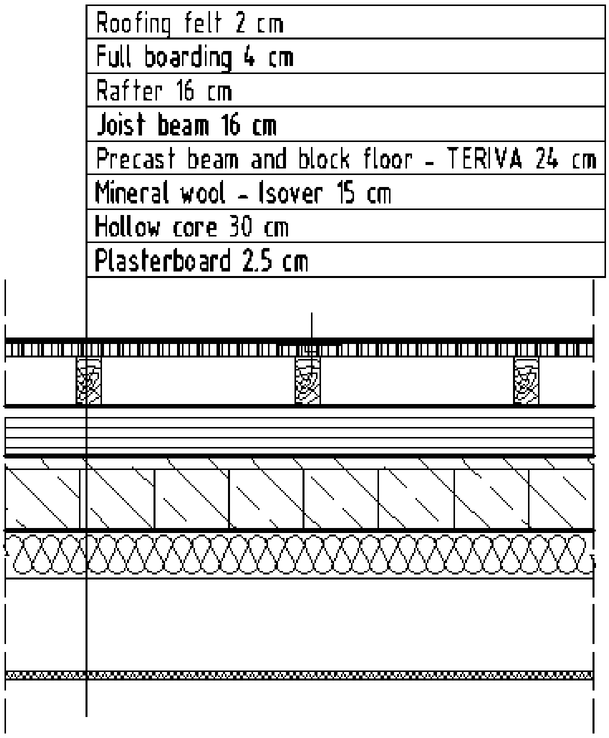


Figure 5.2.3.1.1. Structure of the roof cross section 1-1.

The values for the roof cross section 1-1 were input to PHPP, as shown in Figure 5.2.3.1.2.

Heat transfer resistance [m²K/W] interior R_{si} : 0,10
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Precast beam and block	0,649					240
6.	Mineral wool - Isover	0,030					150
7.	Plasterboard	0,230					25
8.							
			Percentage of Sec. 2	10,0%	Percentage of Sec. 3		Total 79,5 cm

U-Value: 0,133 W/(m²K)

Figure 5.2.3.1.2. Data from PHPP for the roof cross section 1-1.

The obtained U-value for the roof cross section 1-1 is **0,133 W/(m^{2}K)**.

5.2.3.2. Roof – cross section 2-2

The structure of the roof cross section 2-2 is shown in Figure 5.2.3.2.1.

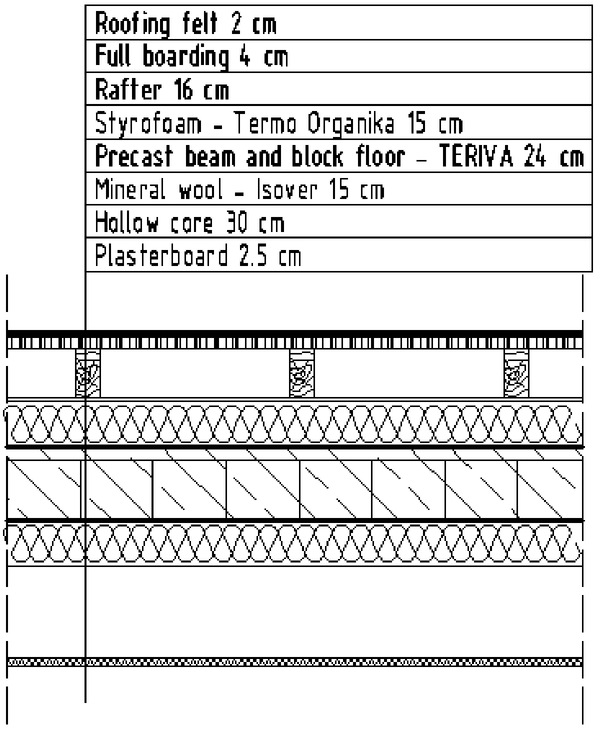


Figure 5.2.3.2.1. Structure of the roof cross section 2-2.

The values for the roof cross section 2-2 were input to PHPP, as shown in Figure 5.2.3.2.2.

Heat transfer resistance [m²K/W] interior Rsi : 0,10; exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Hollow core	0,270					100
5.	Styrofoam - Termo Organ:	0,031					150
6.	Precast beam and block :	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
				Percentage of Sec. 2		Percentage of Sec. 3	Total
				9,0%			88,5 cm

U-Value: 0,085 W/(m²K)

Figure 5.2.3.2.2. Data from PHPP for the roof cross section 2-2.

The obtained U-value for the roof cross section 2-2 is **0,085 W/(m²K)**.

5.2.3.3. Roof – cross section 3-3

The structure of the roof cross section 3-3 is shown in Figure 5.2.3.3.1.

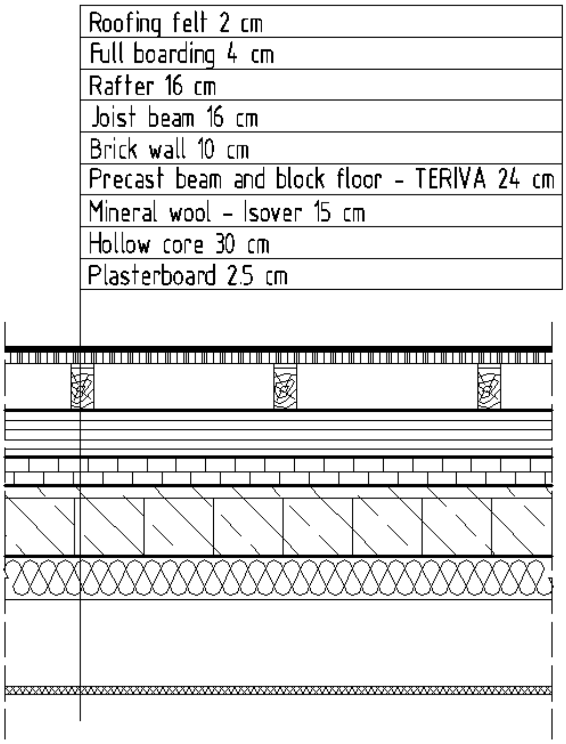


Figure 5.2.3.3.1. Structure of the roof cross section 3-3.

The values for the roof cross section 3-3 were input to PHPP, as shown in Figure 5.2.3.3.2.

Heat transfer resistance [m²K/W] interior R_{si} : 0,10
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Brick wall	0,770					100
6.	Precast beam and block	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
			Percentage of Sec. 2	9,0%	Percentage of Sec. 3		Total
							89,5 cm

U-Value: 0,131 W/(m²K)

Figure 5.2.3.3.2. Data from PHPP for the roof cross section 3-3.

The obtained U-value for the roof cross section 3-3 is **0,131 W/(m^{2}K)**.

5.2.3.4. Roof – cross section 4-4

The structure of the roof cross section 4-4 is shown in Figure 5.2.3.4.1.

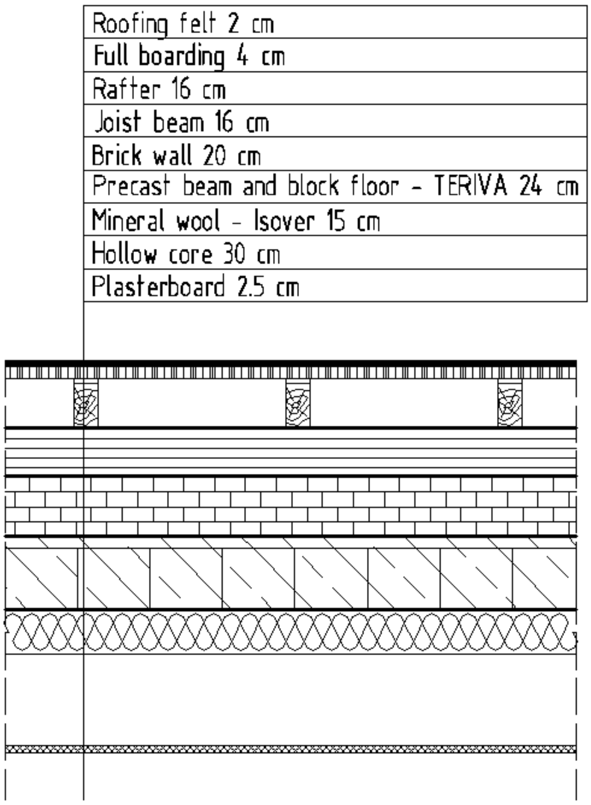


Figure 5.2.3.4.1. Structure of the roof cross section 4-4.

The values for the roof cross section 4-4 were input to PHPP, as shown in Figure 5.2.3.4.2.

Heat transfer resistance [m²K/W]	
interior R_{si} :	0,10
exterior R_{se} :	0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Brick wall	0,770					200
6.	Precast beam and block	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
			Percentage of Sec. 2	9,0%	Percentage of Sec. 3		Total 99,5 cm

U-Value: **0,129** W/(m²K)

Figure 5.2.3.4.2. Data from PHPP for the roof cross section 4-4.

The obtained U-value for the roof cross section 4-4 is **0,129 W/(m^{2}K)**.

5.2.4. Floor slab

5.2.4.1. Elevated floor

The structure of the elevated floor is shown in Figure 5.2.4.1.1.

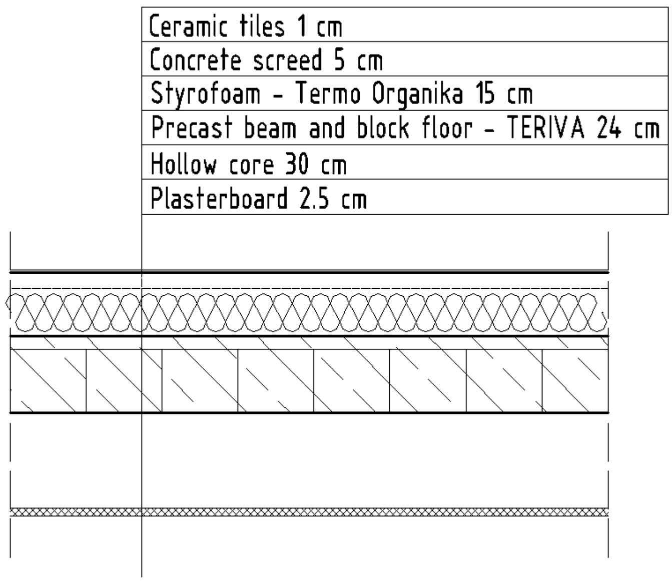


Figure 5.2.4.1.1. Structure of elevated floor.

There was no need for calculation U-Value for the elevated floor, only amounts for thermal inertia.

5.2.4.2. Floor slab

The structure of the floor slab is shown in Figure 5.2.4.2.1.

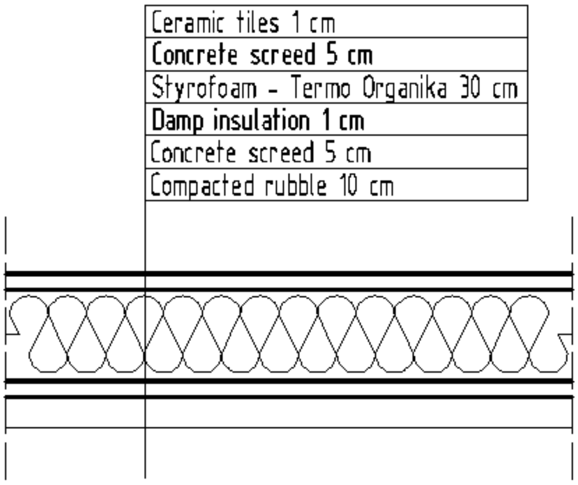
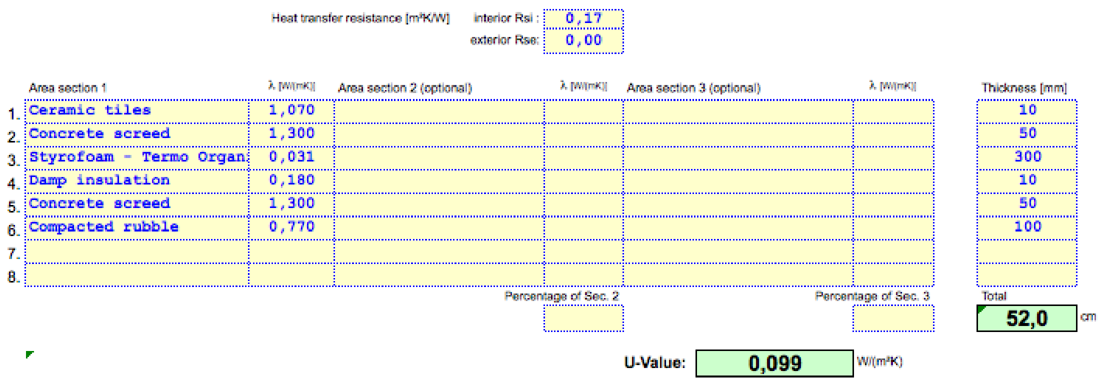


Figure 5.2.4.2.1 Structure of the floor slab.

The values for the floor slab were input to PHPP, as shown in Figure 5.2.4.2.2.



Heat transfer resistance [m²K/W] interior Rsi : 0,17
exterior Rse: 0,00

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Ceramic tiles	1,070					10
2.	Concrete screed	1,300					50
3.	Styrofoam - Termo Organ	0,031					300
4.	Damp insulation	0,180					10
5.	Concrete screed	1,300					50
6.	Compacted rubble	0,770					100
7.							
8.							

Percentage of Sec. 2 | Percentage of Sec. 3 | Total 52,0 cm

U-Value: 0,099 W/(m²K)

Figure 5.2.4.2.2. Data from PHPP for floor slab.

The obtained U-value for the floor slab is **0,099 W/(m^{2}K)**.

5.3. Thermal bridges

5.3.1. General description

According to EN ISO 10211-1 a thermal bridge is a part of the building envelope, in which a uniform thermal resistance is significantly changed by:

1. Total or partial penetration of the building envelope with materials with different thermal conductivity.

2. Change of the materials layers thickness.

3. The difference between internal and external surfaces of partitions, which occur in the connections [48].

As has already been mentioned in the previous chapter, thermal bridges are an issue, which should be given special attention during the designing a Passive House, because they have a significant effect on the house heat balance.

To avoid thermal bridges, the tightness of the envelope in the Passive House should be done as precisely as possible. Therefore, the building envelope has been designed as a continuous closed line covering the entire space of thermal comfort, which is shown in the Figure 5.3.1.1.

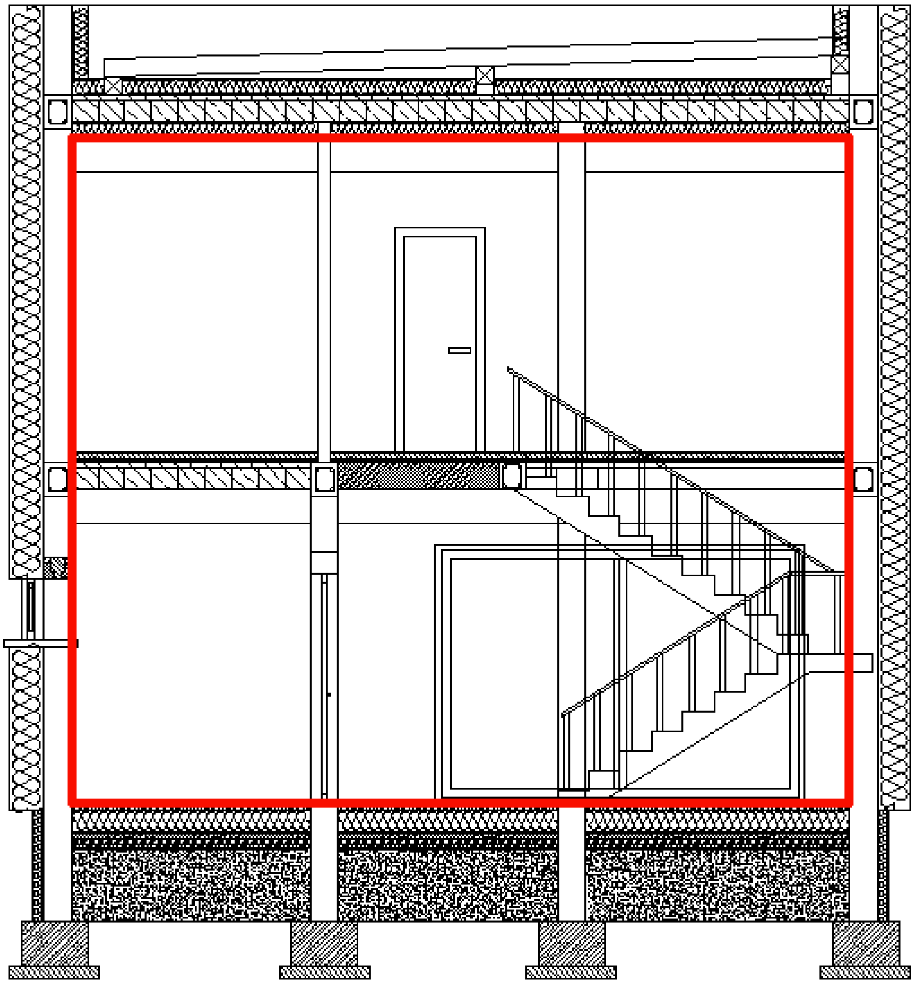


Figure 5.3.1.1. Continuous Passive House envelope.

To achieve this, a special attention should be paid to a way of applying a plaster. The inner layer of plaster must be applied continuously -from the flooring construction to the floor ceiling. On the roof should be used a continuous layer of polyethylene film between the interior and a layer of insulation [47].

Using PHPP program were considered the linear bridges occurring in the conjunctions of: the floor slab with the exterior wall, the corners of exterior walls, the roof with exterior wall, the peripheral bridge occurring in connection of the concrete beam with elevated floor, the staircase slab with exterior wall and also thermal bridges occurring on the perimeters of the windows.
Mentioned thermal bridges are shown in Figure 5.3.1.2.

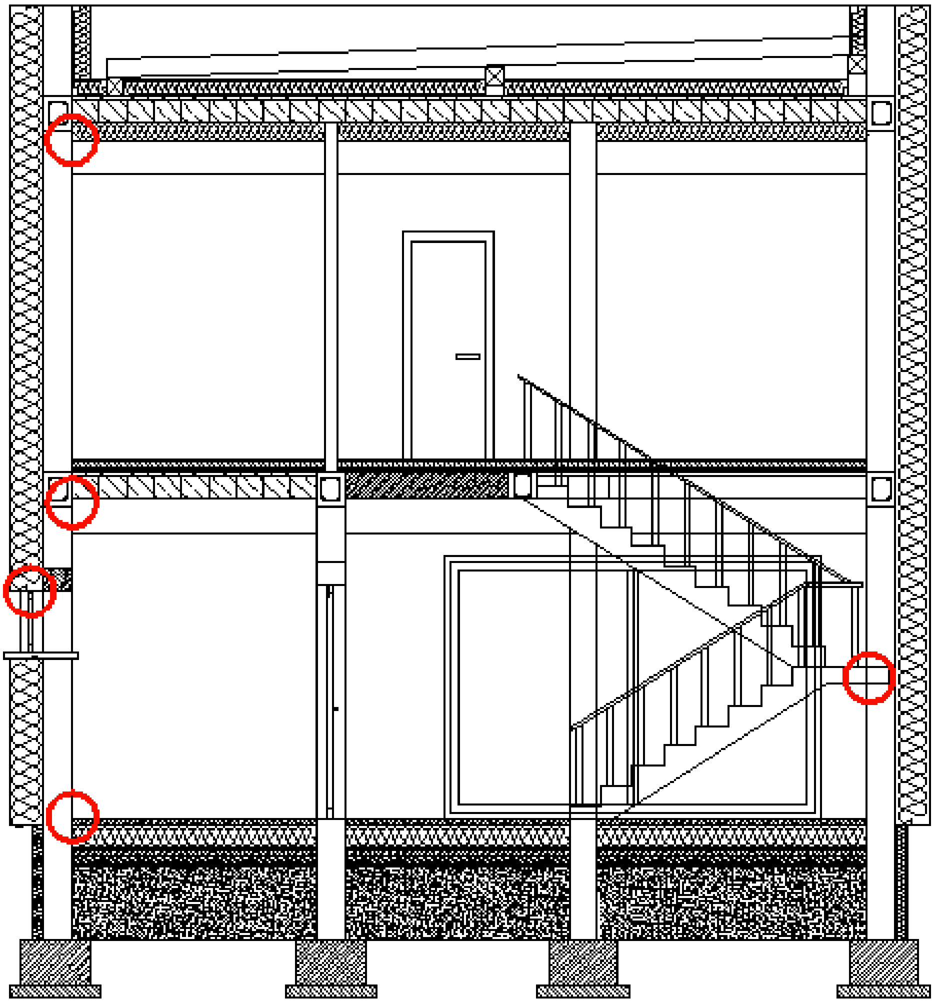


Figure 5.3.1.2. Location of linear thermal bridges.

5.3.2. Thermal bridges calculations

Thermal bridges calculations were made in the THERM 7.2. This program can model two-dimensional heat-transfer effects in building components such as windows, walls, foundations, roofs, and doors; appliances; and other products where thermal bridges are of concern.

This program allowed to obtain the heat flow value, on the basis of which it was possible to calculate the linear heat transfer coefficient Ψ. Then, the obtained values were entered to the PHPP program to „Areas“ Worksheet. The data is automatically carried over to the heating balance in the „Annual Heating Demand“ Worksheet.

THERM allowed also to obtain the maps with the local temperature areas, which may relate directly to problems with condensation, moisture damage, and structural integrity.

Calculated values of the linear heat transfer coefficient are relatively small and some of them have negative values. This may be due to the application of a thick insulation layer, whereby the heat loss through thermal bridges are so small. Thermal bridges, where the linear heat transfer coefficient Ψ is less than 0.01 W/(mK) have a negligible impact on the building heat demand and don't have to be considered. However, It was decided that for the more precise calculations, negative values of Ψ will be also entered to the PHPP Software.

The temperature difference between interior and exterior for all the cases was assumed in ***Δt* = 38**°.

5.3.2.1. Exterior wall corner

The results that have been obtained from the THERM for the thermal bridges of exterior wall corner are shown in the following Figures:

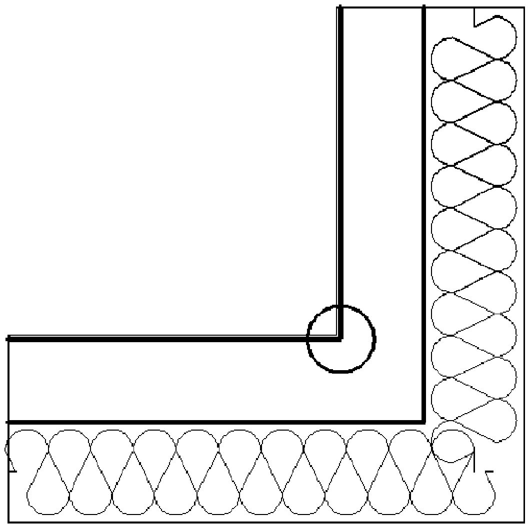


Figure 5.3.2.1.1. Location of the Thermal bridge in the exterior wall corner.

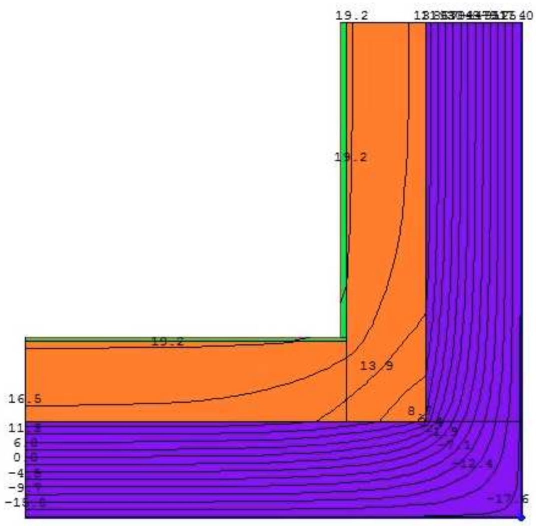


Figure 5.3.2.1.2. Isotherms for the exterior wall corner Thermal bridge. [66]

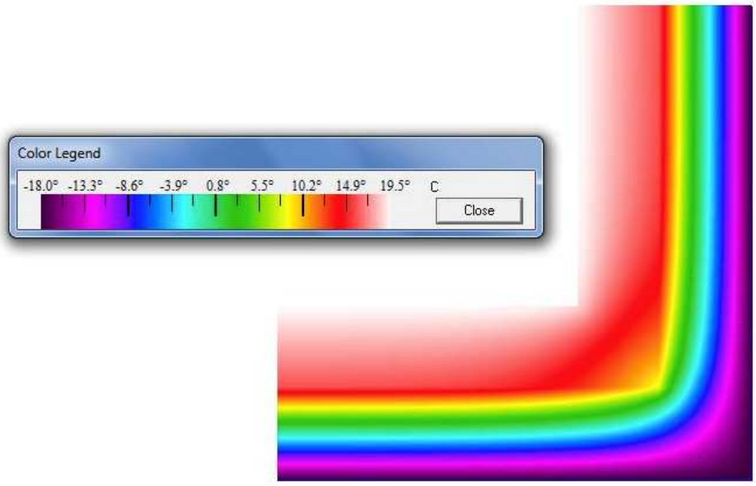


Figure 5.3.2.1.3. Map with the local temperature areas in the exterior wall corner. [66]

The data obtained in the THERM, under which the linear thermal transmittance has been calculated is shown in Table 5.3.2.1.1.

Table 5.3.2.1.1. Values obtained for the exterior wall corner thermal bridge.

U-valueU_1	0.092 W/m^{2}K
U-valueU_1	0.092W/m^{2}K
Length L_1	1.552 m
Length L_1	1.552 m
Heat Flow	8.802 W

The calculated linear thermal transmittance is $\boldsymbol{\Psi} = \mathbf{-0,054}\ \frac{\mathrm{W}}{\mathrm{m\,K}}$.

5.3.2.2. Connection of the exterior wall with the floor slab

The results that have been obtained from the THERM for the thermal bridges in the connection of the exterior wall with the floor slab are shown in the following Figures:

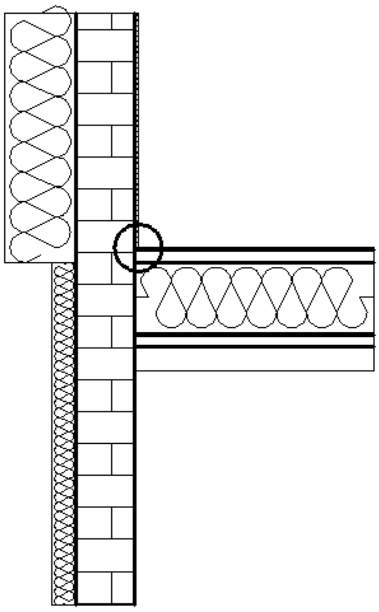


Figure 5.3.2.2.1. Location of the Thermal bridge in the connection of the exterior wall with the floor slab.

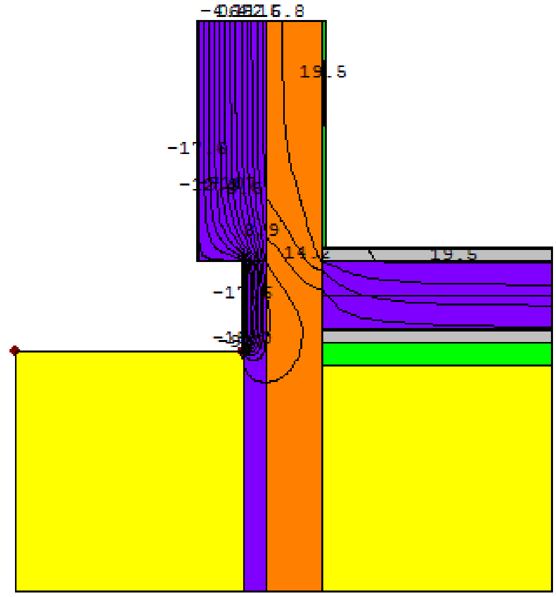


Figure 5.3.2.2.2. Isotherms for the Thermal bridge in the connection of the exterior wall with the floor slab. [66]

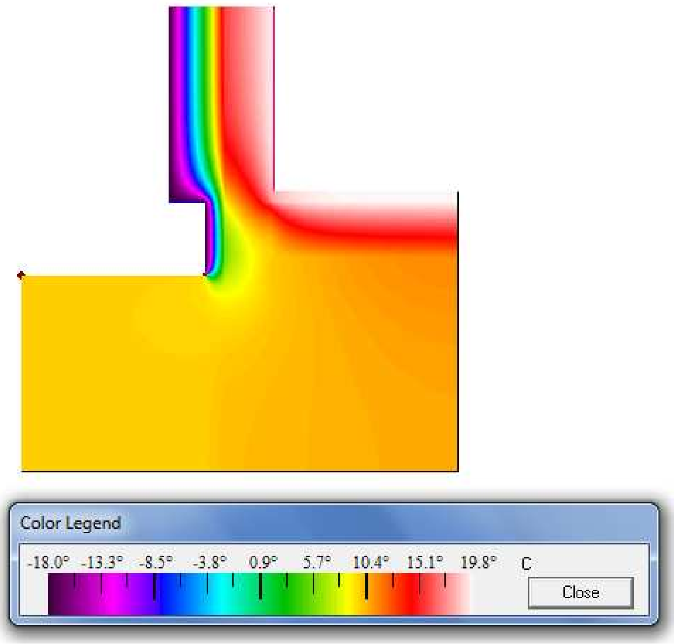


Figure 5.3.2.2.3. Map with the local temperature areas in the connection of the exteior wall with the floor slab. [66]

The data obtained from the THERM, under which the linear thermal transmittance has been calculated is shown in Table 5.3.2.2.1

Table 5.3.2.2.1.Values obtained for the thermal bridge in the connection of the exterior wall with the floor slab. [66]

U-valueU_1	0.099 W/m^{2}K
U-valueU_1	0.092 W/m^{2}K
Length L_1	1.365 m
Length L_1	1.520 m
Heat Flow	6.948 W

The calculated linear thermal transmittance is $\boldsymbol{\Psi} = \mathbf{-0,0}\frac{\mathrm{W}}{\mathrm{m\,K}}$.

5.3.2.3. Connection of the exterior wall with the roof slab

The results that have been obtained from the THERM for the thermal bridges in the connection of the exterior wall with the roof slab are shown in the following Figures:

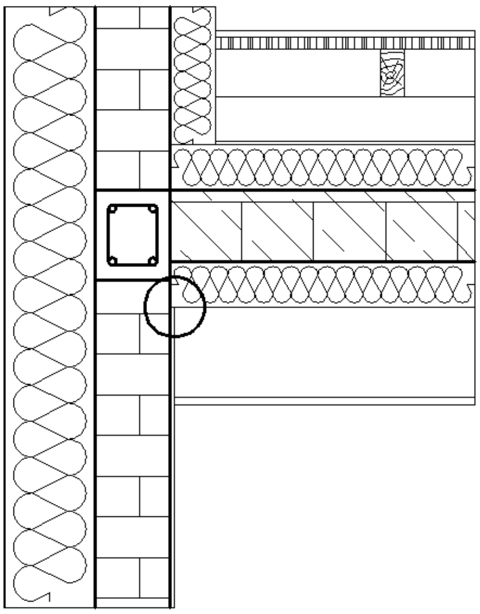


Figure 5.3.2.3.1. Location of the Thermal bridge in the connection of the exterior wall with the roof slab. [66]

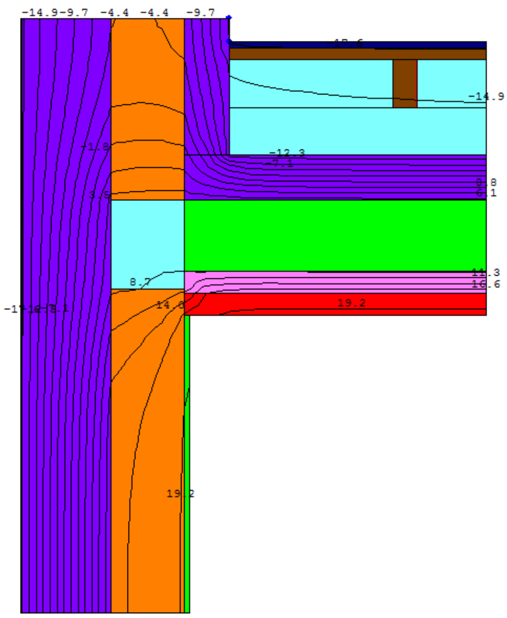


Figure 5.3.2.3.2. Isotherms for the Thermal bridge in the connection of the exterior wall with the roof slab. [66]

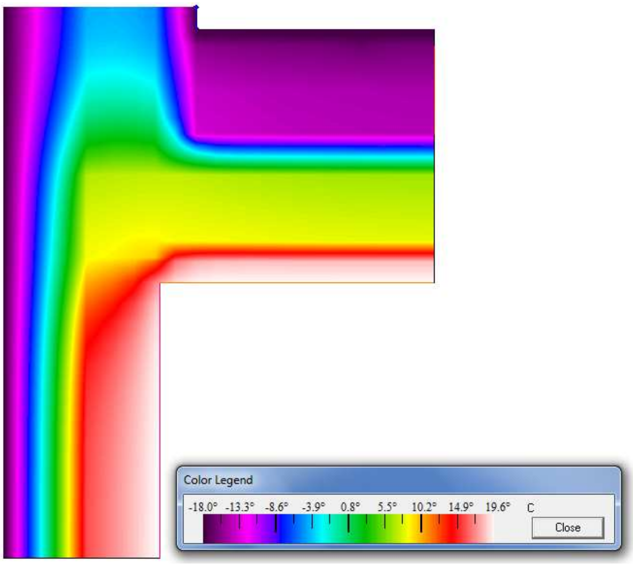


Figure 5.3.2.3.3. Map with the local temperature areas in the connection of the exterior wa l with the roof slab. [66]

The data obtained from the THERM, under which the linear thermal transmittance has been calculated is shown in Table 5.3.2.3.1.

Table 5.3.2.3.1.Values obtained for the thermal bridge in the connection of the exterior wall with the roof slab. [66]

U-valueU_1	0.092 W/m^{2}K
U-valueU_1	0.083 W/m^{2}K
Length L_1	1.567 m
Length L_1	1.920 m
Heat Flow	10.741W

The calculated linear thermal transmittance is $\boldsymbol{\Psi} = \mathbf{-0,021}\,\frac{\mathrm{W}}{\mathrm{m\,K}}$.

5.3.2.4. Connection of the exterior wall with the concrete beam

The results that have been obtained from the THERM for the thermal bridges in the connection of the external wall with the concrete beam are shown in the following Figures:

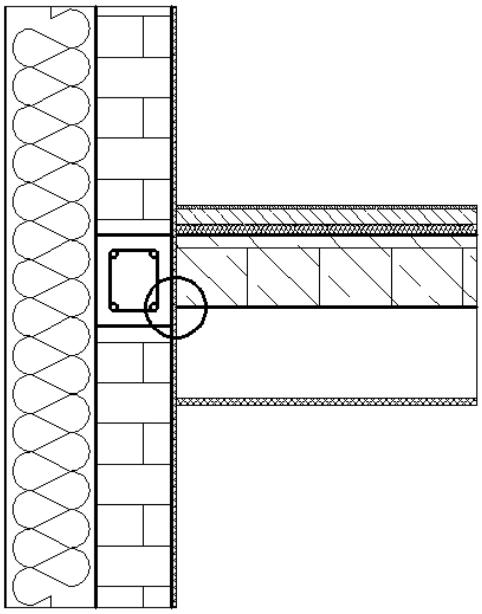


Figure 5.3.2.4.1. Location of the Thermal bridge in the connection of the exterior wall with the concrete beam. [66]

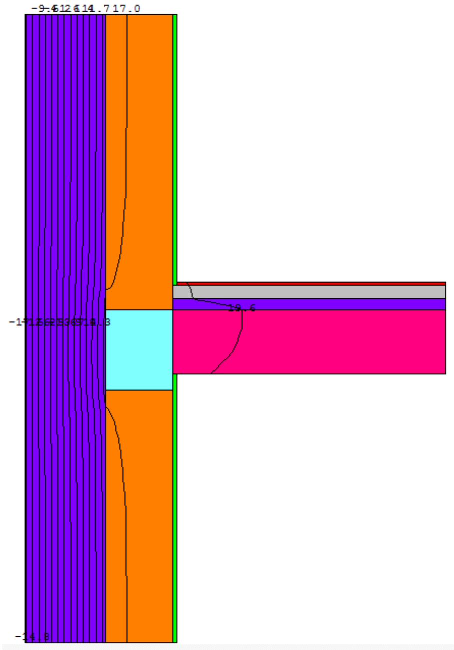


Figure 5.3.2.4.2. Isotherms for the Thermal bridge in the connection of the exterior wall with the concrete beam. [66]

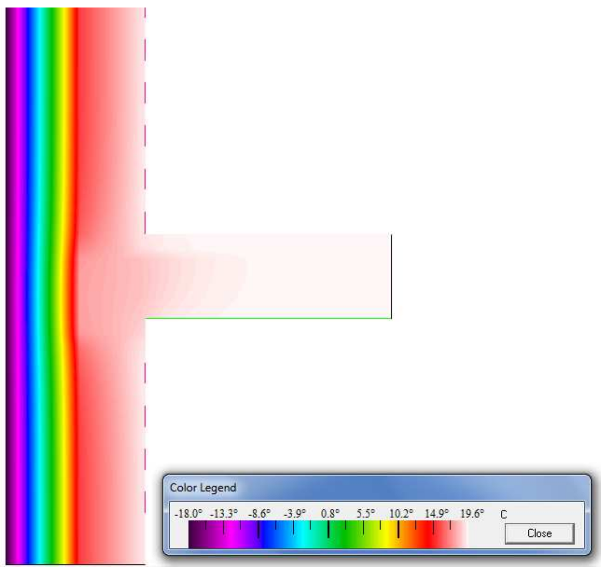


Figure 5.3.2.4.3. Map with the local temperature areas in the connection of the exterior wall with the concrete beam. [66]

The data obtained from the THERM, under which the linear thermal transmittance has been calculated is shown in Table 5.3.2.4.1.:

Table 5.3.2.4.1. Values obtained for the Thermal bridge in the connection of the exterior wall with the concrete beam. [66]

U-valueU_1	0.100 W/m^{2}K
U-valueU_1	0.092 W/m^{2}K
Length L_1	1.338 m
Length L_1	0.662 m
Heat Flow	8.260W

The calculated linear thermal transmittance is $\boldsymbol{\Psi} = \mathbf{0,023}\,\frac{\mathrm{W}}{\mathrm{m\,K}}$.

5.3.2.5. Connection of the exterior wall with the staircase slab

The results that have been obtained from the THERM for the thermal bridges in the connection of the external wall with the staircase slab are shown in the following Figures:

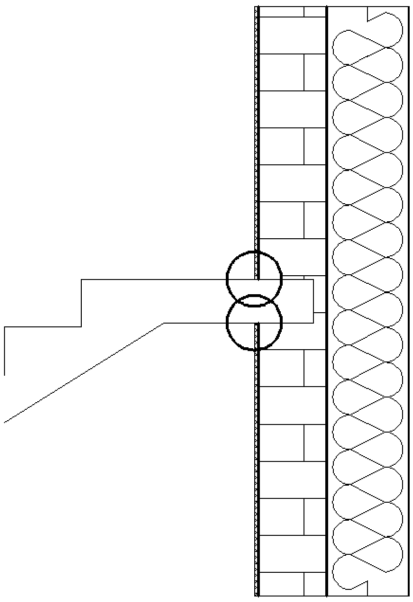


Figure 5.3.2.5.1. Location of the Thermal bridge in the connection of the exterior wall with the staircase slab. [66]

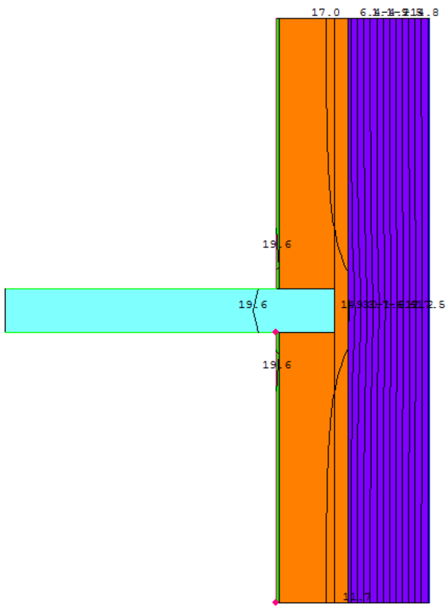


Figure 5.3.2.5.2. Isotherms for the Thermal bridge in the connection of the exterior wall the staircase slab. [66]

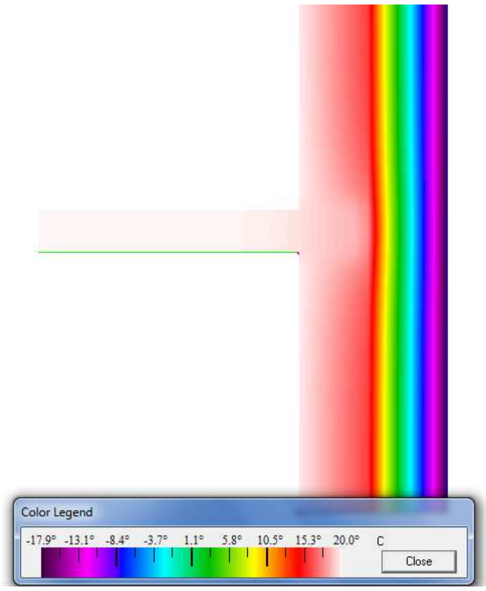


Figure 5.3.2.5.3. Map with the local temperature areas in the connection of the exterior wall with the staircase slab. [66]

The data obtained from the THERM, under which the linear thermal transmittance has been calculated is shown in Table 5.3.2.5.1:

Table 5.3.2.5.1.Values obtained for the Thermal bridge in the connection of the exterior wall with the staircase slab. [66]

U-valueU_1	0.092 W/m^{2}K
U-valueU_1	0.092 W/m^{2}K
Length L_1	1.000 m
Length L_1	1.160 m
Heat Flow	7.602 W

The calculated linear thermal transmittance is $\boldsymbol{\Psi} = \mathbf{0,001}\frac{\mathrm{W}}{\mathrm{m\ K}}$.

5.3.2.6. Connection of the window with the exterior wall

The following Figures for the used windows were taken from the manufacturer's catalog:

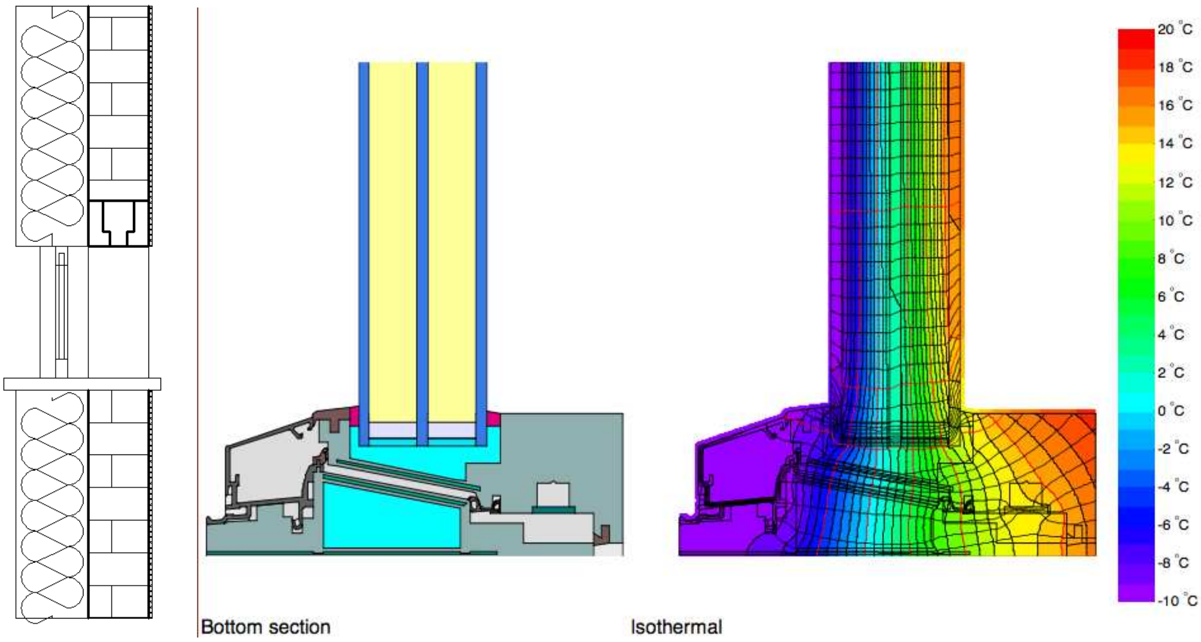


Figure 5.3.2.6.1. Construction of the window and the map with the local temperature areas in the used window.[67]

Thermal data

	U_f-value [W/(m²K)]	Width [mm]	Ψ_g [W/(mK)]	$f_{Rsi=0.25}$ [-]
Spacer			SWISSP. Ultimate PU*	
Bottom	0.72	58	0.021	0.76
Side/top	0.64	58	0.021	

Figure 5.3.2.6.2. Data for the used window taken from the manufacturer's catalog. [67]

For the windows the calculated linear thermal transmittance is $\boldsymbol{\Psi} = \mathbf{0.0}\frac{\mathrm{W}}{\mathrm{m\,K}}$. This value was taken from the manufacturer's catalog.

5.4. Insulation

For the thermal insulation of the house was used a styrofoam with very good insulation properties. Due to the improved composition of graphite added to the styrofoam, the obtained material has a very high thermal insulation – coefficient of thermal conductivity λ amounts in $0.031\ \mathrm{W/(m \cdot K)}$. The walls of the house were insulated with the silver-gray slabs – “Platinum Plus” of Termo Organika company with the thickness of 30 cm.

The roof is insulated with the “Platinum” Styrofoam slabs with the thickness of 15 cm from the outside, placed between roof beams. However, this insulation was not sufficient to achieve the required heat coefficient less than 0.15W/m^{2}K, therefore on the inner side of the roof slab additionally was applied mineral wool ISOVER with the thickness of 15 cm and very good insulation properties – coefficient of thermal conductivity λ amounts in $0.030\ \mathrm{W/(m \cdot K)}$.

For the thermal insulation of the foundation walls was used a styrofoam enriched with compositions of hydrophobic compounds – “Gold Plus” plate from the Termoorganika company. This styrofoam has not only increased resistance to water, but also significantly improved insulating properties compared to other traditionally use styrofoams. [49]

In the guidelines for the passive house the standard heat transfer coefficient for exterior walls, roof and ceiling should not exceed the value of 0.15 W/m^{2}K. However, during performing calculations for designed passive house, it turned out that in order to reach the passive house standard in Polish climatic conditions, it was necessary to decrease the heat transfer coefficient U for the walls and floor to around 0.1 W/m^{2}K.

5.5. Windows

5.5.1. General description

For the Polish climate in a transitional and summer period, windows are acting as solars, so an active reheating is required in the small extent. A bigger problem occurs during the winter season, in the months from March to April when in a central European climate solar energy gains are really small. In the Polish climate is also present another problem, which is low outside temperatures occurring in the months with low sunlight. Accordingly, heat loss during this period are the highest. In the Passive House the bigger windows areas are designed to use of the solar energy, thereby they lead to the higher heat losses, especially in the winter period. Therefore, there are used high quality glazings with the low heat transfer coefficient U, that provide low thermal conductivity with the simultaneous high permeability of the solar energy. This means that they provide more solar energy in the rooms, than caused by them heat losses, even during the winter. [47]

As mentioned earlier, the orientation of the windows on the southern elevation has much better results, due to the fact that in the winter sunlight penetration through the glass is almost perpendicular, and the flow of energy is more advantageous.

In the summer the south oriented glazings are also very beneficial. In the Polish latitude in the middle of summer the sun comes up on the facade relatively late, is then very highly - the result is a narrow band of rays and a small amount of energy. Thanks to this the summer sun load is relatively small. [47]

To maximize solar gains, especially important in the winter period, most of the transparent surface has been located on the southern elevation. It was also decided not to use any of a shading elements, in order to not block the access of the sun and the glazing could fulfil its essential role as a collector. [47]

5.5.2. Cross Ventilation

In the PHPP Software the data to create the cross ventilation between the windows was entered.

Cross ventilation refers to one form of naturally occurring ventilation in a building. It is obtained by having windows in both sides of the room, causing airflow across the space. Positive pressure on the windward and/or a vacuum on the lee side of the building causes air movement across the rooms from the windward to the lee side, provided the windows on both sides of the room are open.

Designing cross ventilation in buildings allows for passive cooling and reduces the reliance on air-conditioning. The cross ventilation principle is like all natural ventilation principles, based on the requirement of ensuring a fresh and comfortable indoor climate. [50]

5.5.3. Data for the selected Window Glazing and Frame

The selected Window Glazing and Frame are approved by a Passive House Institute and have the certificate „Component suitable for Passive Houses: Window Frame".

They are characterized by the high quality of contemporary triple-pane low emisivity glazing and a high quality window frame, which are necessary to maintain a comfortable indoor climate and adequate energy balance, which is particulary important during the winter months.

Also, due to the high thermal quality windows used, heat losess occurring in the connection of the frame with the glazing and the frame with the wall are significantly reduced. [47]

For the passive house windows the important issue is also the proper installation of windows, so to avoid unnecessary heat losses. Windows installed in masonry or concrete walls with exterior insulation should be placed in the plane of the insulation (as shown in Figure 5.5.3.1) and not the plane of the masonry. [51]

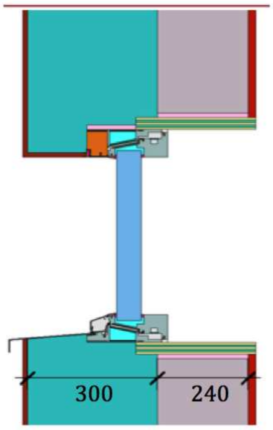


Figure 5.5.3.1. Proper installation of windows in the plane of the insulation.[67]

The type of windows for passive house has been selected in accordance with the division of the regions into climatic zones. Poland is located in a Cold Climatic zone, as shown in Table 5.5.3.2.

Re-gion No.	Name	Cities	Recommended glazing
1	Arctic	Tromso, Murmansk, Novosibirsk, Magadan	Vacuum low-e
2	Cold	Anchorage, Calggary, Regina, Winnipeg, Quebec, Halifax, Reykjavik, Oslo, Stockholm, Warswa, Kiev, Moscow, Ekaterinburg, Urumqi, Yinchuan, Harbin, Ushuaia (AR)	Quadruple glazed low-e
3	Cool-temperate	Vancouver, Seattle, Portland, Salt Lake City, Kansas City, Memphis, Ottawa, Montreal, Portland, New York, Washington, London, Paris, Berlin, Vienna, Rome, Zagreb, Budapest, Sofia, Istanbul, Erzurum, Groznyy,Teheran, Beyneu, Muynak, Tokmok, Mazari Sharif, Chengdu, Wuhan, Shanghai, Beijing, Seoul, Tokio, Christchurch (NZ South Island), Comooro Rivadavia AR, Rio Grande (AR), Conchi (CL)	Triple glazed low-e
4	Warm-temperate	San Francisco, Los Angeles, Albuquerque, Juarez, Chihuahua, Casablanca, Lisbon, Porto, Bilbao, Toulouse, Marseilles, Corsica, Sardinia, Sicily, Aqaba, Gaza, Kathmandu, Guilin, Quanzhou, Elizabeth, Melbourne (Southern Australia), Wellington (NZ Northern Island), Santiago (CL), Antofagosta (CL), Buenos Aires(AR) , Vedna (AR), Cape Town (ZA), Post Elizabeth, Quthing	Double glazed low-e
5	Warm	Campala (Lake Victoria), Hawassa (ET), Johannesburg, Hawaii, Mexico City, Zcatecas, Torreon, Monclova, Quito, Trujillo	Double glazed
6	Hot	Matamoros (MX), Veracruz (Mx), Palm Bay, Maiami, Homestead, Havana, Caparazon (VZ), Salvador (BR), Rio de Janeiro (BR), Florianopolis (BR), Windhoek, Huambo, Boma, Libreville, Port Harcourt Nigeria, Maputo, Beira, North Vietnam, Las, Burma, Papua New Guinea (not Southern part)	Double glazed anti-sun
7	Extremly hot, often humid	Southern California, Corpus Christi, Houston, New Orleans, Talahassee, Amazonas, Santa Cruz de la Sierra, Sahara, Central Africa, Mbandaka, Basako, Mdagascar, Saudi Arabia, Yemen, UAE, India, Sri Lanka, Bangladesh, Burma, Cambodia, Indonesia, Philippines, Northern Parts of Australia	Triple glazed anti-sun

Figure.5.5.3.2. Example cities in each regions and recommended glazing. [52]

5.6. Mechanical Ventilation

5.6.1. Ventilation unit

To achieve the passive standard, instead of normally used in standard buildings in Poland natural ventilation, the mechanical supply-exhaust ventilation with heat recovery is applied. It allows for a significant reduction of heat losses, as well as providing a constant air exchange in the building. The ventilation unit is equipped with a heat exchanger - recuperator, where the air is exhausted out of the building gives off the heat to the air supply into the building. [58]

In the designed house is used a Zehnder ComfoAir 200 ventilation unit which is for use in residential settings with high ventilation demand. As we can read in specification of this unit, it combines maximum comfort, simple operation and high efficiency with flexible integration.

The integrates cross-counterflow heat exchanger achieves efficiencies of up to 95%. For user comfort it means no unpleasant draft effects, because the supply air is heated almost to room temperature even when external temperatures are around freezing.

This recuperator is equipped with the frost protection. It prevents the condensate in the ventilation unit from freezing. The frost protection settings provide from this by variably reducing the supply air volume.

This ventilation unit is also provided with an automatic bypass, which ensures pleasantly cool ait inside building during hot summer nights in the transition periods with strong sunshine. [53]

The Zehnder ComfoAir 200 ventilation unit is characterised by its compact design. The supply and extract air connections are located on the top the unit, those for the outside and exhaust air are on the bottom.

In the case of mechanical ventilation, it is important to proper placement the ventilation system. The ventilation unit was placed on the wall in the storage room. All rooms must be provided with adequate size vents, enabling for the seamless air flow also when the door closed.

When planning ventilation ducts particular attention was paid to make them as short as possible, so that the heat loss through ventilation ducts were as low as possible.

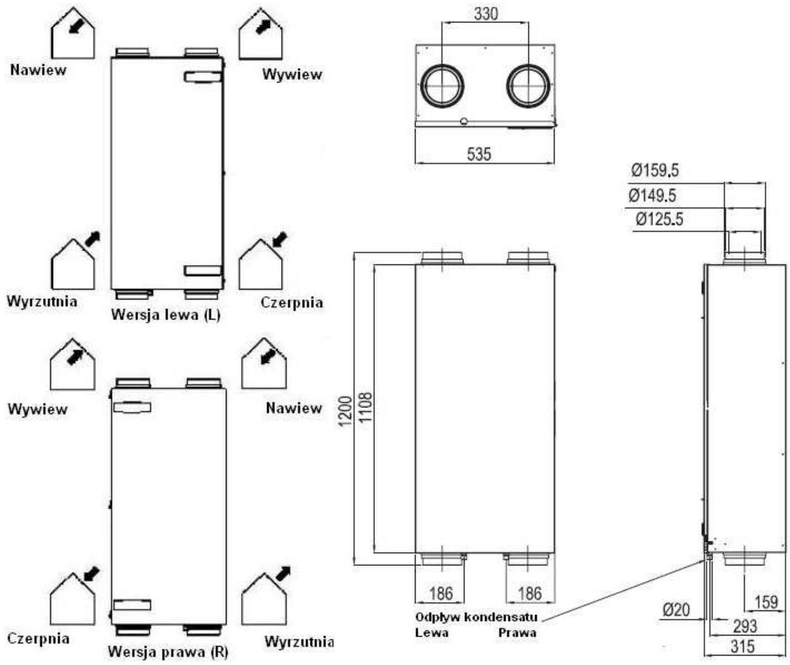


Figure 5.6.1.1. Dimensions of the selected ventilation unit. [53]

During the heating period in Polish houses there is frequently encountered a problem of dry air - air humidity decreases significantly. As is it known, dry air negatively affects our health, because it causes irritation to the eyes, difficult breathing, and can also contribute to reduction of immunity. Therefore, it is very important to take care not only of the favourable temperature in the house, but also of the right amount of water vapour in the air. [54]

The Zehnder enthalpy plate exchanger provides a hygienic ideal solution for excessively dry air in the winter. Not only heat, but also up to 65% of the moisture contained in the extract air is transformed from the extract air to the supply air. Supply air flows is kept completely separate so there is no transfer of odors or bacteria. [53]

The main advantages of the heat recovery unit with the enthalpy exchanger use are:

- significant increase of climate comfort in the winter (higher relative humidity in the rooms),
- no risk of the heat exchanger freezing, which provides constant ventilation and lower energy consumption by a recuperator,
- a significant reduction in energy demand compared to a system: the recuperator with the usual exchanger plus an air humidifier. [55]

In Figure 5.6.1.2. We can see how the recuperator's membrane permeable water and heat, while blocking the penetration of gases, impurities and odors.

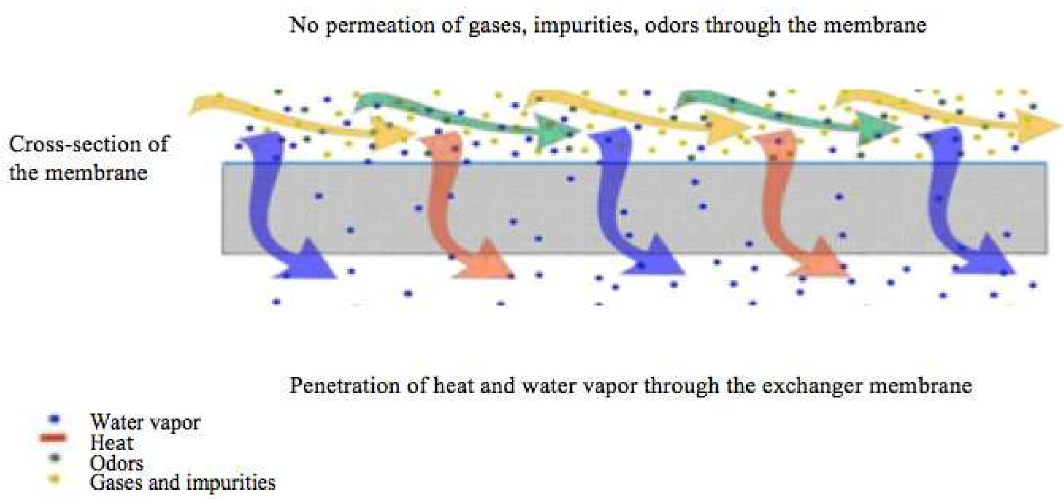


Figure 5.6.1.2. Recuperator with the moisture recovery. [55]

As it was already mentioned, for the heat recovery from exhaust air in winter is used mechanical ventilation where the most important element is recuperator.

However, in the addition of the of heat recovery a recuperator in the summer heat can also recover coolness. If the outdoor temperature will be higher than the temperature in the house, a cooler exhaust air will cool down the hot supply air. By this process, in a well-insulated house where the direct incidence of the solar radiation on the windows is cut off from the outside, the thermal comfort can be very long maintain without any additional cooling. [56]

However, there are periods during the year and even during the day when we do not want any heating or cooling recovery from extract air. Such a situation occurs usually in the summer at night. Outside air temperature is then lower than the temperature inside. We would like to cool down the heated during the hot day house. Heat recovery from the extract air loses then any sense, because it would cause unnecessary in this case heating of supply to the rooms air. In this case should start automatically work bypass in the heat exchanger. Recuperator acts then like a normal supply and exhaust ventilation unit without heat recovery/cooling. [56]

In the designed passive house is used a recuperator with an automatic bypass, which depending on the outer and inner measured temperatures and from desired temperature in the house, will allow the panel to work with the heat or cold recovery, or switch it to work with bypassing the heat exchanger. [56]

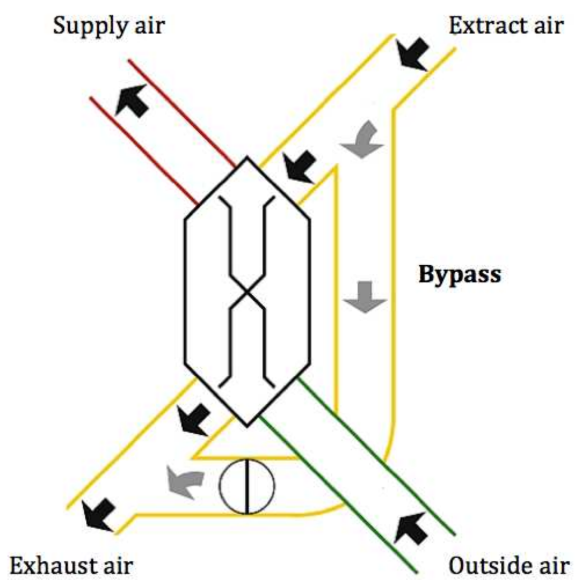


Figure 5.6.1.3. Functional diagram of the recuperator with a bypass. [57]

5.6.2. Distribution of the ventilation areas

In the "Ventilation" Worksheet can be found tools helping in the design dimensioning of the ventilation system and the recommendations which are: supply air – 30 m^3/h per person, exhaust air: from the wet rooms, including the bathrooms: - 40 m^3/h, showers and toiles - 20 m^3/h, kitchens from 40 to 60 m^3/h. These are the maximum values .

The values of supply and exhaust air were changed in order to achieve the required value of the heat demand for passive house. [47] However, changes have been made in such a way, that the living comfort in the house is still provided. The amount of supplied to the building air, provides the compensation of extract air to avoid the effect of positive or negative pressure in the building. The quantities of the supply and extract air are shown in Table 5.6.2.1.

Table 5.6.2.1. Quantity of supply and extract air.

Type of room	Area	Volume	Change rate	Quantity of Supply air	Quantity of Extract air
-	[m^2]	[m^3]	[1/h]	[m^3/h]	[m^3/h]
GROUND FLOOR					
Vestibule	3,40	8,50	1	Transfer area	
WC	2,67	6,68	3		30
Pantry	2,14	5,35	1		10
Kitchen	8,52	21,30	2		50
Living room + dining room	20,17	50,43	1	50	
Hall 1	8,22	20,55	1	Transfer area	
Utility room	2,14	5,35	-		10
FIRST FLOOR					
Hall 2			1	Transfer area	
Bedroom 1	8,39	20,98	1	30	
Bedroom 2	8,76	21,90	1	30	
Bathroom	9,02	22,55	3		30
Bedroom 3	12,91	32,28	1	30	
Wardrobe	3,12	7,80	1		10
			Total	140	140

There are determined 3 zones for the ventilation system which are: supply air zone (living room + dining room, 3 bedrooms), transfer area (vestibule, 2 halls) and extract air zone (kitchen, pantry, WC, utility room, wardrobe and bathroom).

In the described arrangement the directed air flow from the rooms in supply zone through the transfer zone to the rooms, where the air is extracted. In this way the problem of odors and impurities propagation in the apartment is avoided. [47] This solution results in removal of impurities and moisture in areas where it is produced (no transfer of pollution to other rooms), while fresh air is delivered to the rooms and the bedrooms, where it's the most needed.

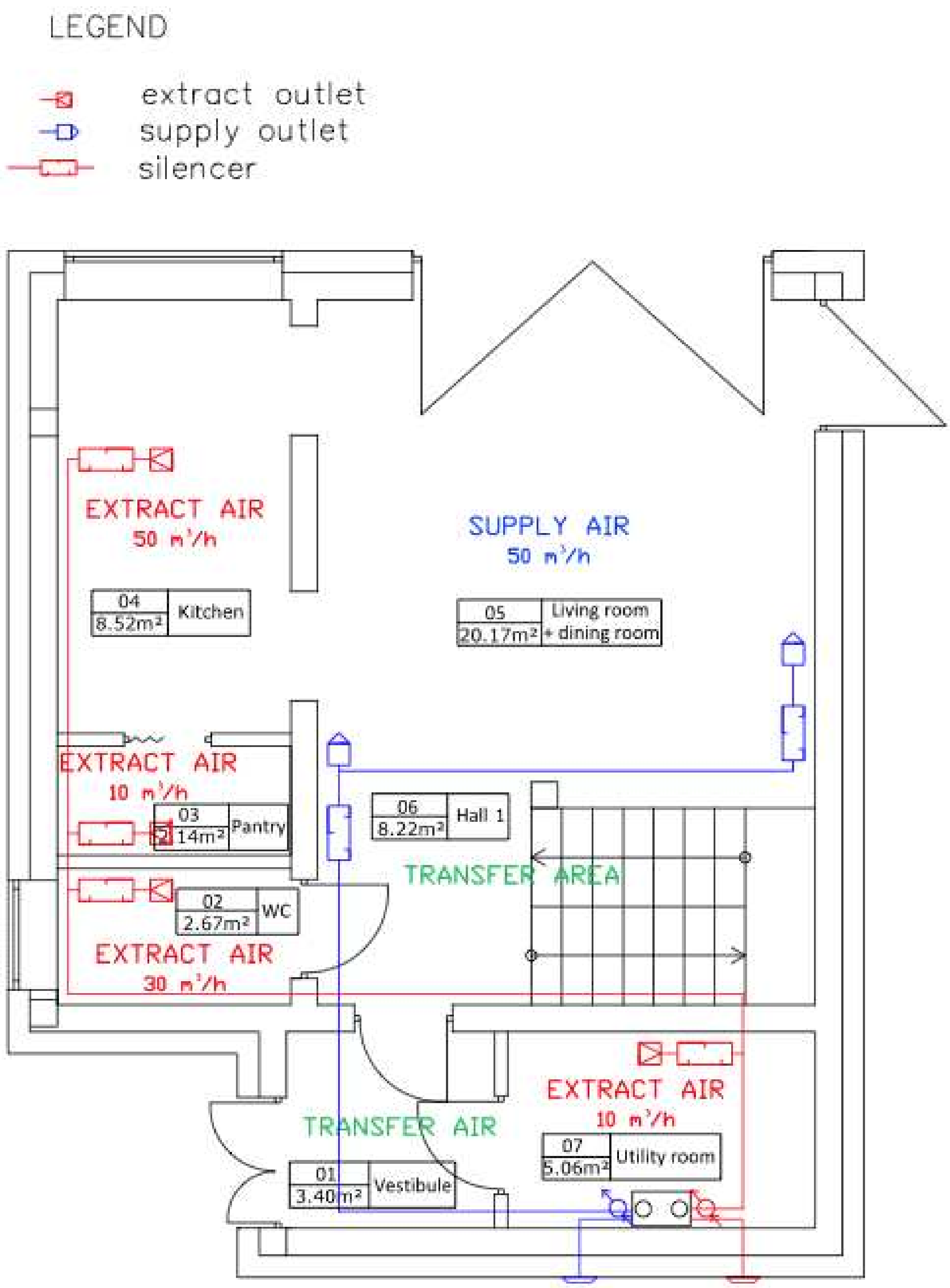


Figure 5.6.2.1.Distribution of the ventilation areas (supply, transfer and extract) on the ground floor.

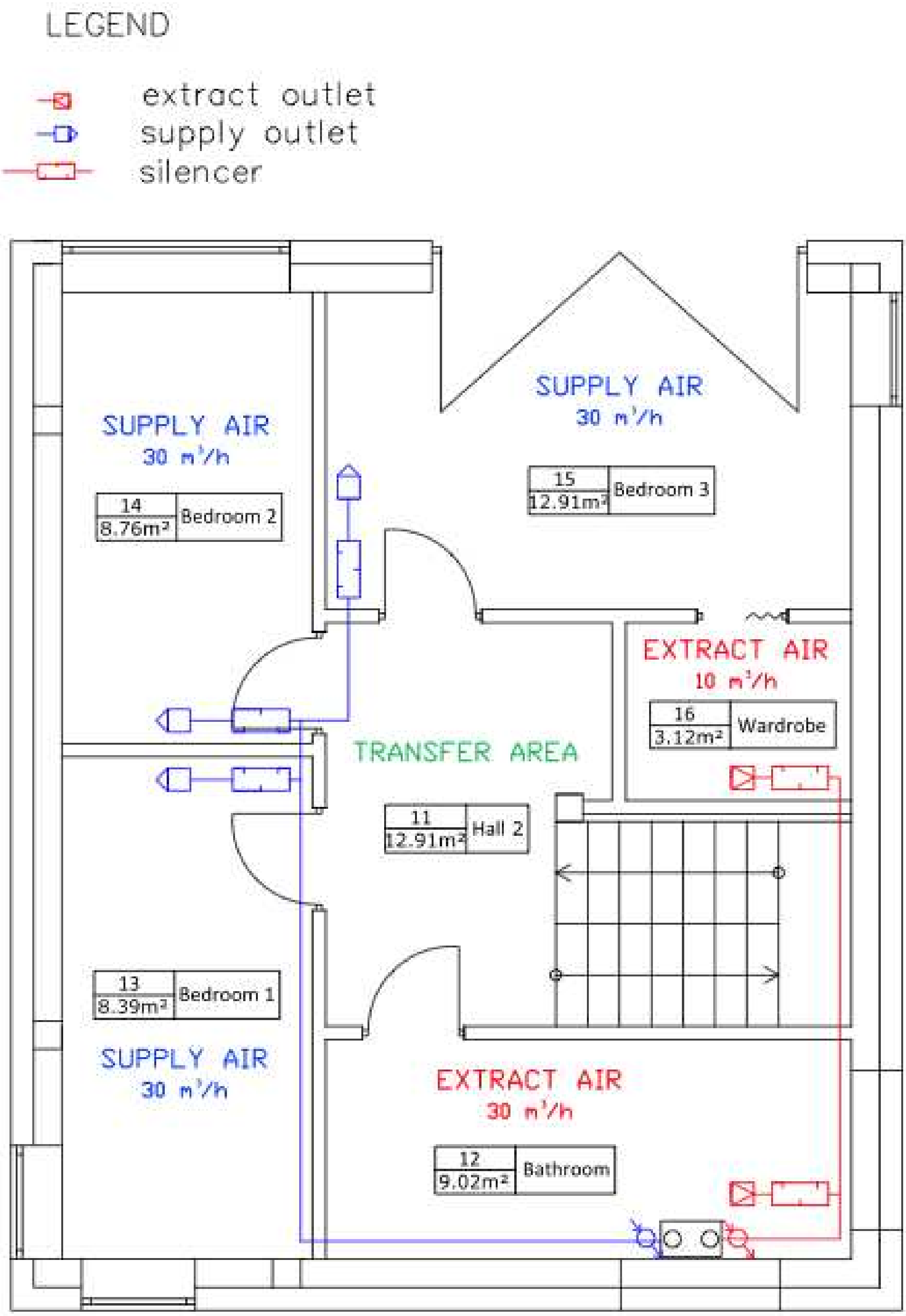


Figure 5.6.2.2. Distribution of the ventilation areas (supply, transfer and extract) on the first floor.

5.7. Domestic Hot Water

5.7.1. Distribution of the DHW pipes

DHW pipes and hot water tank were located within the insulated building envelope. As a result, heat loss related to these components bring benefit to heated interiors, and as well eliminate the problem of freezing. During the design of the channels distribution, particular attention was paid to make them as short as possible, thereby not only saves investment costs, but also the heat losses. Insulation of the channels that was used allows to reduce energy losses, at the same time reducing the heating of the building during the summer period. [47]

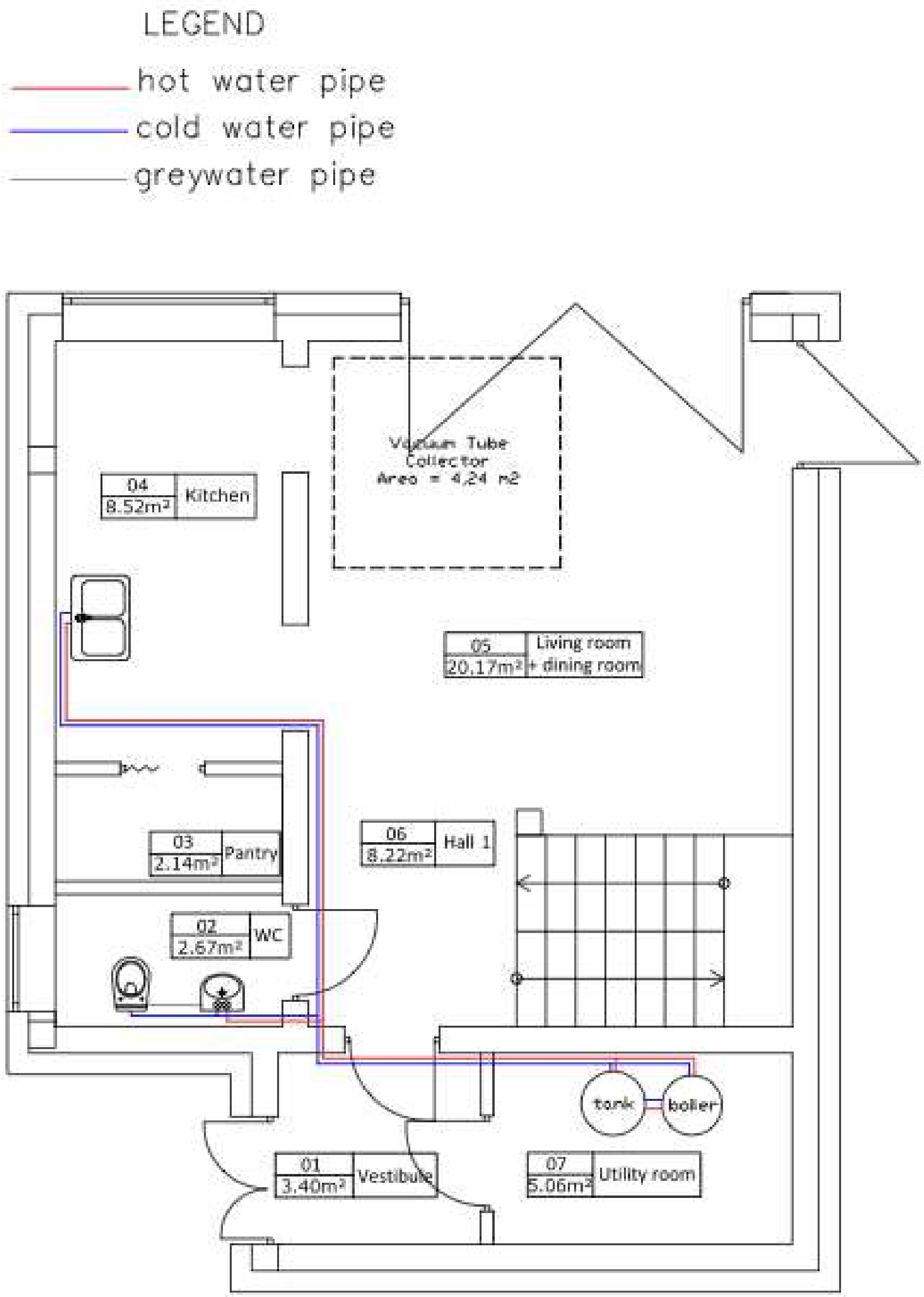


Figure 5.7.1.1.Distribution of the water pipes on the ground floor.

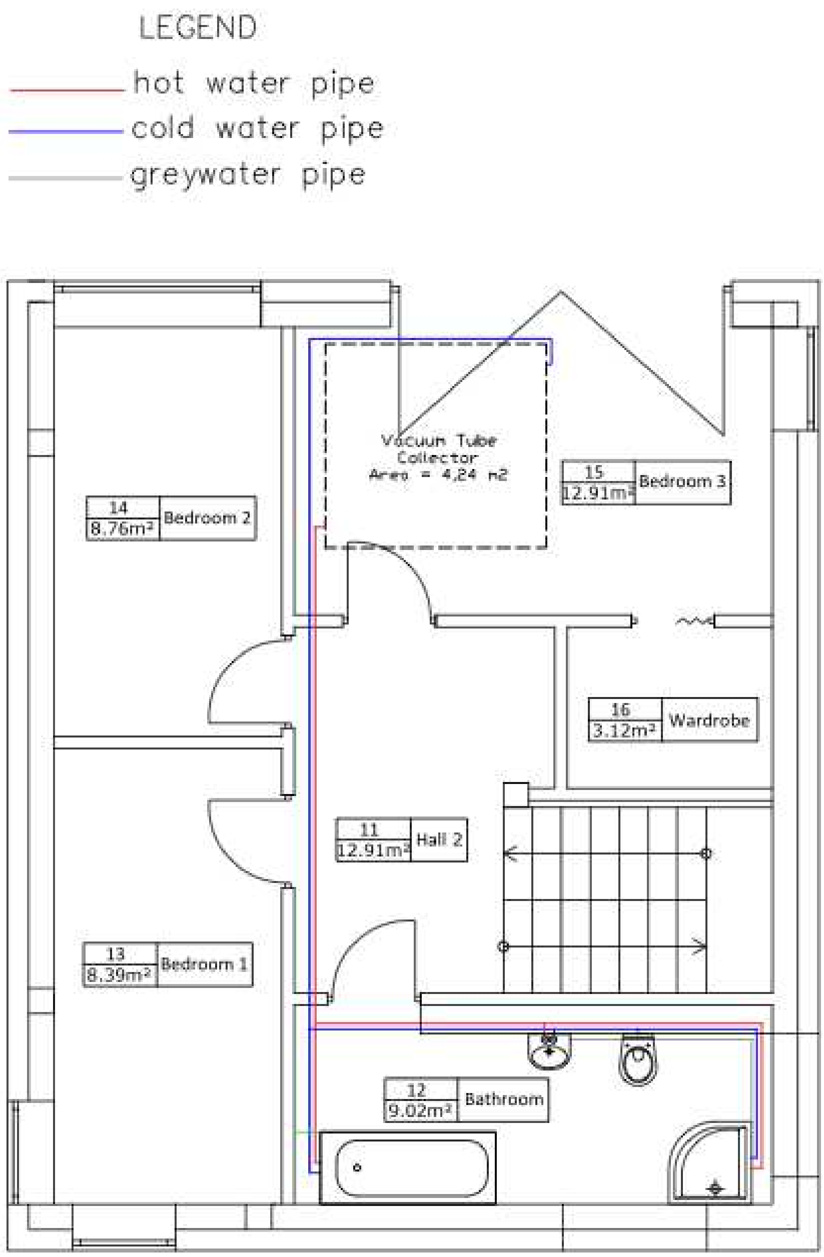


Figure 5.7.1.2.Distribution of the water pipes on the first floor.

5.7.2. Stratified Solar Tank

For this dwelling is used the Stratified Solar Tank Strato-Therm+. This tank has 3 main functions: it acts as a storage vessel for solar thermal systems, an indirect water heater and a buffer tank for hydronic applications. This stratified solar tank utilizes the natural buoyancy of heated water to efficiently stratify the hydronic heating water that is stored within the tank. [58]

Advantages of the Stratified tanks are mainly - simple construction, and effective separation of the layer with high temperature from the lower space with low temperature. This provides the maximum efficiency of solar collectors. In the stratified tank it is located a corrugated stainless steel coil which is used to heat the domestic hot water. It is also an effective solution to protecting the system against deposits and a decrease in performance. [59]

Figure 5.7.2.1. Construction of the chosen Stratified Solar Tank. [58]

The principle of thermal stratification, in the stratified Solar Tank is based on a natural process. Since warm water is lighter than cold water, it will ascend until it reaches a layer of warmer water or the top of the tank. This process facilitates the efficient utilization of solar heat. [60] It also significantly increases the comfort of using a combi boiler because for the users immediate disposal is relatively large amount of heated water.

The consumption of hot water is done from the top of the tank, waiting time for the hot water is very short and user does not have to wait until the entire contents of the tank will be heated. This process is shown in Figure 5.7.2.

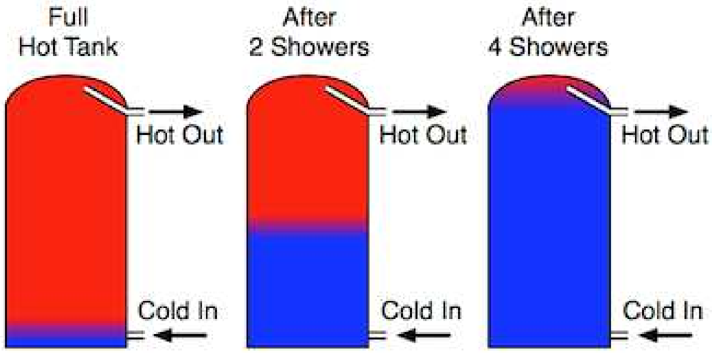


Figure 5.7.2.2. Consumption of hot water in stratifed tank. [61]

Also thanks to the layer water placement in the stratified tank, a small water intake do not run the boiler, which extends its life and saves gas. [62] The more stable the thermal stratification, the higher the efficiency of the solar heating system and the comfort for the user by providing reliably sufficient amounts of hot water. [60]

Solar stratified tank is equipped with a module for cooperation with a solar collector, which has been located in the southern part of the roof. Thanks to the use of the pump with adjustable efficiency, the module adjusts the temperature of the water flowing into the reservoir to the current needs and the intensity of a solar radiation. First, the pump is running at low speed to create a higher temperature in order for loading of the upper part of the tank. If due to low sun exposure it is not possible, then the efficiency of the pump is set at a level that guarantees the lowest temperature difference between the solar collector and the water temperature flowing into the buffer. In fact, when the solar radiation intensity is high, then the unit supplies with the high temperature the upper part of the buffer. However, if the intensity decreases the module supplies with the a low-temperature the lower part of the buffer.

As a result, on the one hand, at midday occurs quick heating of the upper buffer layer, on the other hand, in the morning and in the afternoon we are able to take advantage of even a small amount of solar energy reaching the collector. [59]

5.7.3. Vacuum tube solar collectors

To prepare the domestic hot water the vacuum tube solar collectors are used. There are placed in the southern part of the roof. These collectors convert solar energy into usable heat that can be used for the heat domestic hot water. Vacuum tube collectors are about 30% more efficient compared to flat plate collectors and are ideally suited in solar systems for domestic water heating. They are characterized by very low heat loss, thanks to the vacuum located in the collector pipes.

Figure 5.7.3.1. Vacuum tube solar collector. [63]

Due to the rounded surface of the absorber, vacuum tube collectors allow for the passive sun tracking throughout the whole day. Absorption surface of the vacuum collector is exposed to sunlight maximally. Therefore, here is no need for any additional mechanical devices rotating the collector. [63]

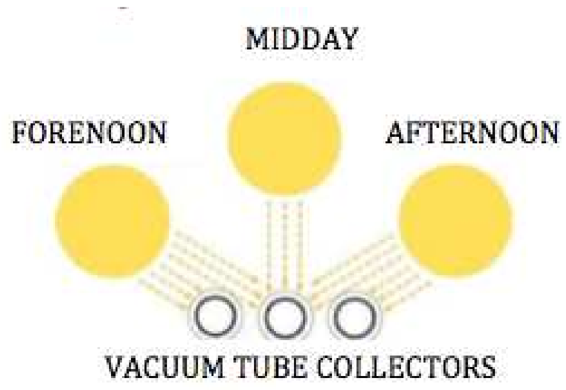


Figure 5.7.3.2. Vacuum tube collectors allow for the passive sun tracking throughout the whole day. [63]

Chapter 6

Calculations for the Passive House with Passive House Planning Package (PHPP)

6. Calculations for the Passive House with Passive House Planning Package (PHPP)

6.1. Introduction

PHPP Software is a tool for the design of passive buildings, thermo modernization and design energy-efficient buildings. “It is compatible with international norms (ISO 13790) and well validated with dynamical simulation tools as well as with measured data. It is especially adapted to high performance buildings and can be used to verify Passive House requirements. The planning package comprises many tools specifically useful for the design of high performance buildings.” [47]

The Passive House Planning Package PHPP consists of a calculation workbook and a handbook. It prepares an energy balance and calculates the annual energy demand of the building based on the user input relating to the building's characteristics.

The calculations obtained in the program are the basis for the certification of passive houses. The program was developed at the Institute of Passive House in Darmstadt, Germany.

This chapter of the dissertation contains the informations about each of the Worksheet in PHPP which relates to designed dwelling. The Worksheets will be briefly described, as well as the data entered and the obtained results.

All the PHPP worksheets can be found in the Annex 1.

The PHPP input sequence for the designed building is shown in Figure 6.1.1.

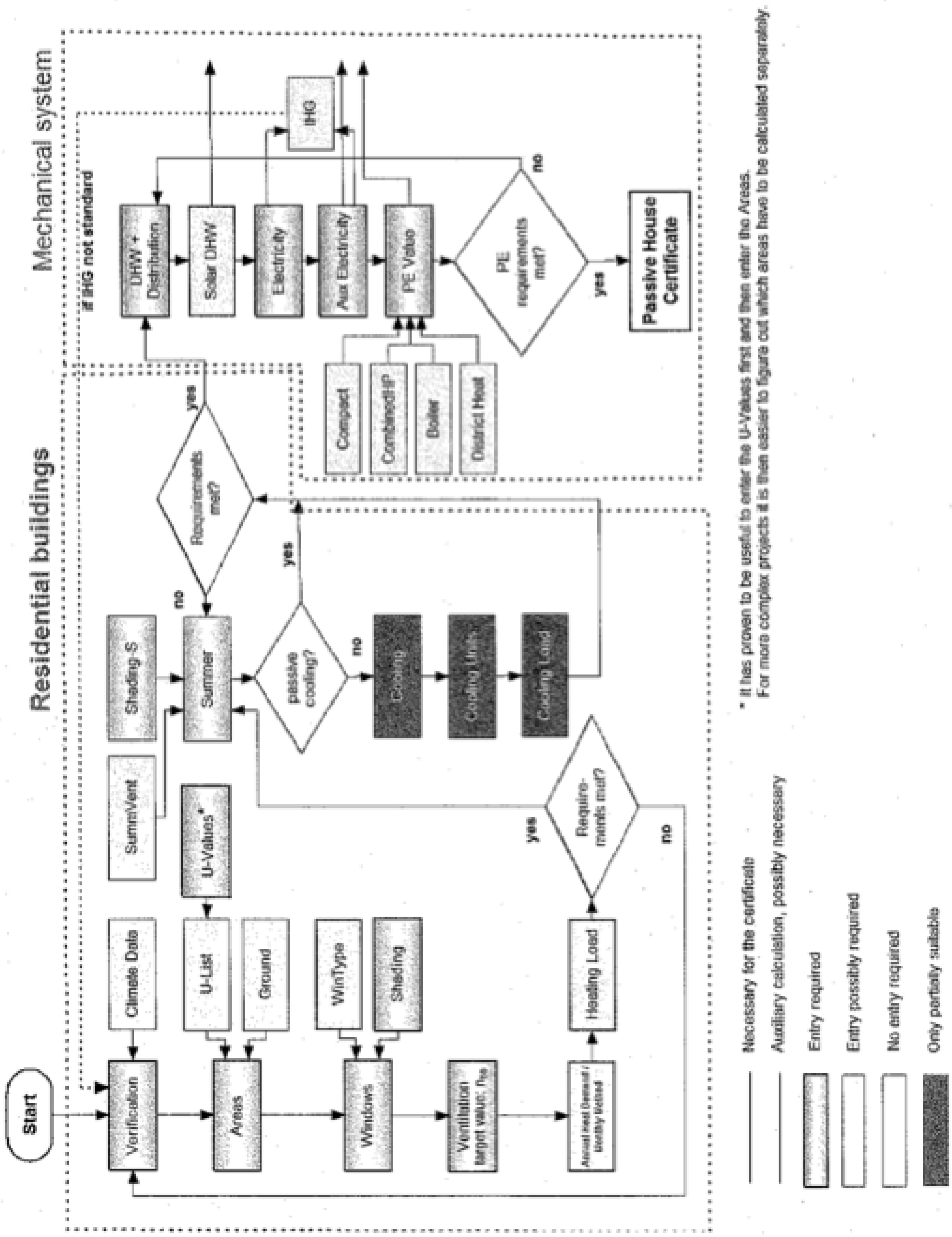


Figure 6.1.1. PHPP input sequence for residential buildings. [51]

6.2. Worksheets description

6.2.1. “Verification“ Worksheet

In this worksheet user can enter the data concerning the building such as: address, type of building, climate zone in which the building is located, enclosed volume and expected number of occupants, enclosed volume and interior temperature. The values entered in this Worksheet are as follows:

- interior design temperature: default value 20℃
- type of building: residential
- planned number of occupants: 4
- verification: the monthly method in accordance with EN 13790, using monthly climate data to determine the sum of the monthly balances during the heating period. Monthly method provides greater precision than the Annual method.

In this worksheet are also shown results cells whether the certification criteria have been met. The most important of them are:

- Specific annual heating demand
- Space heating load
- Cooling and dehumidification demand, if applicable
- Cooling load, if applicable
- Frequency of summer overheating, if applicable
- Specific Primary Energy demand (the maximum value is 120 kWh/(m^2a))
- Air leakage test results

The most important values we receive in this Worksheet are as show in Table 6.2.1.1.:

Table 6.2.1.1. Results obtained in the "Verification" Worksheet

	Obtained Value	Requirement for Passive House
Annual Heating Demand [kWh/(m^{2}a)]	14,17	15
Heating load [W/m^2]	16	10
Frequency of overheating (>25°) [%]	6,8	10
Space heating and cooling, dehumidification, DHW, Auxiliary Electricity and household electricity [kWh/(m^{2}a)]	82	120
Pressurization test result n_{50} [1/h]	0,6	0,6

The condition for Heating Load is not fulfilled, however according to PHPP requirements it is enough if only one of the two is fulfilled, either the specific space heating demand or the heating load.

6.2.2. "Areas" Worksheet

In the „Areas" Worksheet were entered the data related to building thermal envelope. Therefore there are not taken into account the surfaces inside the thermal envelope, such as walls or ceilings.

To simplify the calculation, wall surfaces were divided according to the side of the word and to the type of the exterior wall covering: lime plaster or wooden facade panels. Surface of the wall was calculated by subtracting elements such as lintels, concrete beam and doors, using the „User Subtraction" column. Windows are automatically carried over from „Windows" Worksheet to the „areas" Worksheet and substracted from the corresponding wall area. In the Areas thermal bridges, were also taken into account elements such as the floor slab, concrete beam in the exterior walls, columns, and doors and windows lintels (all of the bridges were calculated also separately for the wall surface covered with plaster and with wooden facade panels).

For a precise calculations the roof's area is divided for several parts. Entries input to the PHPP program are show in Table 6.2.2.1.

Table 6.2.2.1. Surface thermal bridges.

Building element description	Area [m^2]
Exterior wall south (plaster)	6,3
Exterior wall north (plaster)	23,3
Exterior wall west (plaster)	37,7
Exterior wall east (plaster)	28,1
Exterior wall south (panels)	7,2
Exterior wall north (panels)	8,3
Exterior wall west (panels)	0,1
Exterior wall east (panels)	6,9
Floor slab	51,6
Lintels – windows (plaster)	1,6
Lintels – windows (panels)	3,2
Lintels – door (plaster)	0,3
Lintels – door (panels)	0,3
Roof – joist beam 1	1,4
Roof – joist beam 2	1,4
Roof – joist beam 3	1,4
Roof - insulation	52,5
Roof - gutter	1,2
Wall – concrete beam (plaster)	0,7
Wall – concrete beam (panels)	1,2
Column (panels)	1,2
Column (plaster)	2,9

In this Worksheet were also considered the Linear Thermal Bridges. The data entered in the PHPP is shown in Table 6.2.2.2.

Table 6.2.2.2. Linear thermal bridges.

Building element description	Quantity	User determined length [m]	Ψ [W/(mK)]
Windows + doors (jamb)	1	89,30	0,021
Staricase slab	1	3,60	0,001
Roof – exterior wall	1	30,91	-0,021
Floor slab – exterior wall	1	30,91	-0,092
Exterior wall corner	4	5,34	-0,054
Concrete beam	1	30,91	0,023

The treated floor area is the living space or useful area. It is thus a measure of the utilisation of the building, so only areas that are within the thermal envelope are included.

6.2.3. “U-List“ Worksheet

This worksheet allows to generate a summary with the description of the building, the overall thickness and the U-value that are taken from „U-Values“ worksheet. In this worksheet there are also some U-Values for typical building assemblies, that can be chosen by the user.

6.2.4. “U-Values“

In the “U-Values” Worksheet are listed all of the partitions occurring in the building. This worksheet allows for calculation of the overall transfer coefficient of all these building elements.

The transfer coefficient of building partitions is calculated in accordance with ISO 6946, using the formula:

$$\mathrm{U} = \frac{1}{\mathrm{R_{si}} + \mathrm{R_1} + \mathrm{R_2} + \cdots + \mathrm{R_n} + \mathrm{R_{se}}}$$

where:

$R_1 \ldots R_n$ – Thermal resistance of individual construction layers, $1 \ldots n$

R_{si}, R_{se} - Thermal resistence at interior and exterior surfaces in compliance with ISO 6946 [65], taken from Table 6.2.4.1.

Direction of Heat Flow			
	Upward	Horizontal	Downward
R_{si} [m²K/W]: Thermal Resistance of the Interior Surface	0.10	0.13	0.17
R_{se} [m²K/W]: Thermal Resistance of the Exterior Surface	0.04		
R_{se} [m²K/W]: Thermal Resistance of the Below Ground Exterior Surface	0		

Figure 6.2.4.1. Thermal resistance at interior and exterior surfaces. [65]

In this Worksheet have to be entered the heat transfer coefficients U for every partition and the corresponding area A.

The total heat loss depends from the temperature difference determines the value H_t which consists of the heat losses ($U * A$) and losses due to thermal bridges ($\Psi * l$). Calculations are automatically continue in the "Heat Load" Worksheet.

6.2.5. “Ground“ Worksheet

In this Worksheet were entered the data for heat losses of below-ground building elements. Entries input in this Worksheet are as follows:

- The calculation method for: Slab on the grade, which is also for insulated floor slab
- Thermal conductivity for Wet Sand/Gravel, Moist Clay: λ =2 W/(mK)
- Volume Specific Heat Capacity for Wet Sand/Gravel, Moist Clay: $\rho_c = 2\ \mathrm{MJ/(m^3K)}$

- Floor slab area (exterior dimensions): A = 69 m^2
- Floor slab perimeter: 34,4 m‘
- Floor slab U-value: $U_f = 0{,}099\ \mathrm{W/(m^2K)}$
- Orientation of the perimeter insulation: vertical
- Perimeter Insulation Width/Depth: 1 m
- Perimeter Insulation Thickness: 0,12 m

The rest of the necessary data is entered automatically from other worksheets.

In this Worksheet are obtain the results for the reduction factor to ground for “Annual Heating Demand“ Worksheet, the Design Temperature for “Heating Load Worksheet“ and the Design Temperature for “Cooling Load“ Worksheet.

The results for this Worksheet are as follows:

Table 6.2.5.1. Results for the “Ground” Worksheet.

Ground reduction for “Annual Heating Demand“ Worksheet	0,63
Design Temperature for “Heating Load“ Worksheet	6,40

Monthly Average Ground Temperatures for Monthly Method which was also obtained in this Worksheet is presented in Table 6.2.5.2.

Table 6.2.5.2. Monthly Average Ground Temperatures for Monthly Method.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average Value
Winter	7,5	6,4	6,4	7,7	9,9	12,4	14,5	15,7	15,6	14,3	12,1	9,6	11,0
Summer	8,3	7,2	7,3	8,6	10,7	13,2	15,3	16,5	16,4	15,1	12,9	10,4	11,8

6.2.6. “Windows“ Worksheet

“Windows“ Worksheet is particularly important because heat losses and gains of the windows have a great impact on the energy balance of a Passive House. Therefore, they have to be calculated very carefully.

The entered data in this Worksheet is related to the window side of the world orientation, deviation from north, angle of inclination from the horizontal, as well as the dimensions of the window. Data input in the “Windows“ Worksheet is presented in Table 6.2.6.1

Table 6.2.6.1. Data for the entered windows.

Quantity	Description	Deviation from north [°]	Angle of inclination from the horizontal [°]	Length	Height
1	South	180	90	2,00	1,45
1	South	180	90	3,30	2,35
2	North	0	90	1,40	0,60
1	North	0	90	1,00	1,45
2	East	90	90	1,00	1,45
1	East	90	90	1,00	0,60
2	West	270	90	1,40	0,60
1	West	270	90	1,00	1,45
1	South	180	90	2,00	1,45
1	South	180	90	3,30	2,35

A large impact on the amount of the lost heat through the window has also quality of the window installation. In the PHPP individual windows are differentiated from windows which are adjacent to each other. Installed edges has and important influence on the U-value, so it should be determined very precisely. For the jamb which has no contact with the building envelope the installation factor is “1“ and for windows that are abutted symmetrically against each other the installation factor is “0“.

For all the windows the entered value was “1“, because all windows are separated and the jambs have contact with the thermal envelope.

Values of average thermal bridge heat loss coefficient of the installation, were taken from the manufacturer's catalog for the passive house:

Position		EIFS	Timber construction wall	Insulated formwork blocks
Bottom	[W/(mK)]	0.016	0.020	0.017
Side/Top	[W/(mK)]	0.008	0.017	0.010
$U_{W,instal.}$	[W/(m²K)]	0.63	0.65	0.64

Figure 6.2.6.1. Average thermal bridge heat loss coefficient. [67]

Important results from this Worksheet, concerning the annual transmission losses through the windows and heat gains from solar radiation are presented in Table 6.2.6.2.

Table 6.2.6.2. Transmissions losses and heat gains for the word directions.

Window area orientation	Transmission losses [kWh]	Heat gains [kWh]
North	181	76
East	197	198
South	1063	2638
West	181	172
Σ	1623	3084

6.2.7. "WinType" Worksheet

This worksheet contains the data for window glazing and frames. They can be selected form the given in this worksheet list and then the corresponding data will be entered into appropriate columns.

However, the user can also enter new glazing window and frame and enter appropriate values from the catalog.

The g-value and U_g-value taken from the catalog for the window glazing:

- g-value: 0.49 W/m^{2}K
- g: 0.5 [-]

Thermal characteristics for the window frame from the catalog that was input to PHPP is shown in the Figure 6.2.7.1.

	U_f-value [W/(m²K)]	Width [mm]	Ψ_g [W/(mK)]
Spacer			SWISSP.
Bottom	0.72	58	0.021
Side/Top	0.64	58	0.021

Figure 6.2.7.1. Thermal characteristics for the window frame. [67]

6.2.8. “Shading“ Worksheet

This worksheet calculates a total Shading Factor for glazing surfaces, during the heating periods.

For the Shading Factor value, the influence has such an elements as: Horizontal Obstruction Shading Factor, Vertical (Reveal) Shading Factor and Additional Shading Factors. Each of the factors indicates the percentage of solar radiation reaching the window, reduced by the projected shading elements. When window is completely unshaded a shading factor is equal to 100%, and when the window is completely shaded the shading factor is equal to 0%.

The values which were input in this worksheet are:

- Height of the shading object: 0.0 m (for every type of window)
- Horizontal distance: 0.0 m (for every type of window)
- Window reveal depth: 0.05 m (for every type of window)
- Distance from glazing edge to reveal: 0,08 m (for every type of window)
- Overhang depth: 0.0 m (for every type of window)

- Distance from upper glazing edge to overhang: 0.0 m (for every type of window)
- Additional shading reduction factor: 80% (for every type of window), means that all windows are unshaded in 80%

  There were design additional shading elements, such as trees. In the summer they are protecting from the incidence of sunlight to the rooms, and in the summer when the trees lose their leaves, the sun's rays can freely get into the house interior.

Obtained results in this Worksheet for the Shading Reduction Factor are listed in Table 6.2.8.1.

Table 6.2.8.1. Results from the „Shading" Worksheet for the Summer reduction factor r_s.

Orientation	Glazing Area [m^2]	Reduction factor r_s
North	2,42	78%
East	2,79	77%
South	19,25	79%
West	2,42	77%
Horizontal	0,00	100%

6.2.9. "Ventilation" Worksheet

In this worksheet user can input data about the used ventilation system.

Data entered in this Worksheet:

- Type of ventilation system: Balanced PH Ventilation (for a building which is a PH)
- Wind protection coefficient *e*: 0.07 (for a building in a suburban development with several sides exposed to wind action)
- Wind protection coefficient *f*: 15 (for a building with several sides exposed)
- Air Change Rate at Press. Test: n_{50} = 0.6h^{-1} (the maximum value for the air change rate at 50Pa pressure difference)
- Net Air Volume for Press. Test: 531 m^3 (the volume of heated space)

- Supply air per person: 30 m^3/h (default value)
- Selection of ventilation unit with heat recovery: Central unit within the thermal envelope

For the quantity of the extract from the rooms air, the values has been changed, as shown in Table 6.2.9.1.

Table 6.2.9.1. Quantity of the extract air for all the rooms.

Type of room	Kitchen	Bathroom	WC	Other
Quantity	1	1	1	3
Extract air requirement per room $[m^3/h]$	50	30	20	10
Total Extract Air Requirement $[m^3/h]$	140			

The most important value obtained in this Worksheet is Effective heat recovery efficiency $\eta_{eff,HR}$, which describes the percentage of heat recovered from extract air. For the selected Ventilation unit – ComfortAir 200 Zehnder this value amounts 92%.

However, this value is often unrealistically positive, that is why from the obtain value it was subtracted 12%. The final result of Effective heat recovery efficiency equals then:

$$\eta_{eff,HR} = 92\% - 12\% = \mathbf{80}\%$$

There are also presented following results:

- Average air flow rate: **108 m^3/h**
- Average air change rate: **0,41 1/h**

The average air change rate should not fall below 0,3 h^{-1} for reasons of indoor air hygiene. It shouldn't be also to high, because then the indoor air will get to dry during the heating period.

The considerable transmission heat losses can also cause the heat which flows through the ventilation ducts the ventilation unit and the insulated building envelope.

Table 6.2.9.2. Values for the supply and extract air ducts.

	Length [m]	Nominal width [mm]	Insulation Thickness [mm]	Thermal Conductivity [W/mK]	Ψ-value [W/(mK]
Supply air duct	1,90	100	50	0,04	0,284
Extract air duct	1,90	100	30	0,04	0,370

6.2.10. “Annual Heating Demand“ Worksheet

In this section there are summarized all of the heat losses and gains, which are calculated according to the Figure 6.2.1.0.1.

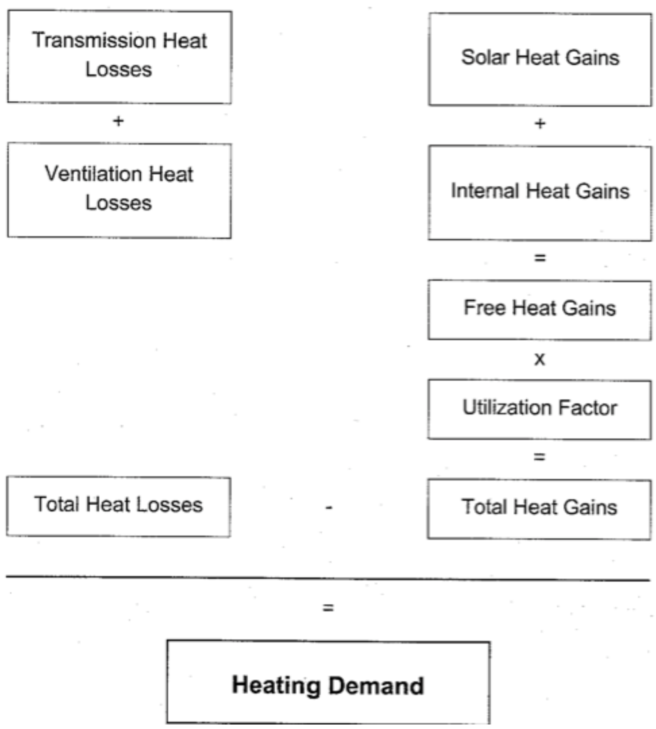


Figure 6.2.10.1. Energy balance diagram. [51]

All the values in this sheet are automatically retrieved from other Worksheets, so no entries are required in “Annual heating demand worksheet”.

The “Annual Heating Demand“ Worksheet contains such informations as: Heating demand balance, Heat losses, (Transmission heat losses Q_T, Window transmission losses, Thermal bridges, Ventilation heat losses), Heat gains (Internal heat gains, Solar radiation).
All the calculation in PHPP program are based on the European Standard EN 13790.

In this Worksheet is also obtained graph chart for the Heating energy balance, showing the Heat flows in two columns, which are divided into parts that correspond to different fractions of total heat losses and heat gains, is presented in Figure 6.2.10.2.

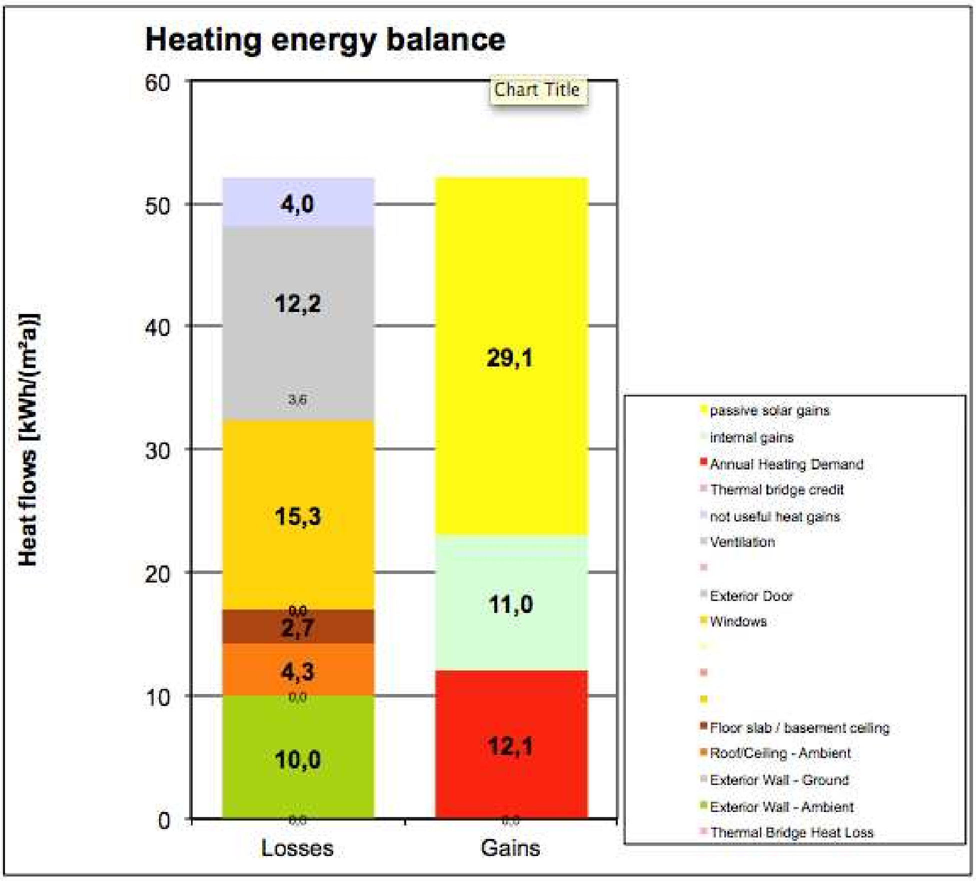


Figure 6.2.10.2. Heating energy balance. [51]

The Annual Heating Demand Q_H = **12 KWh/(m^{2}a) < 15 KWh/(m^{2}a)** → Requirement is met.

6.2.11. "Monthly Method" Worksheet

In the „Monthly Method" Worksheet the energy balance is calculating using an energy balance for every month of the year. All the energy data are retrieved from the „Annual Heating Demand" worksheet.

In this worksheet there is graphically illustrated monthly heating demand, specific gains and losses:

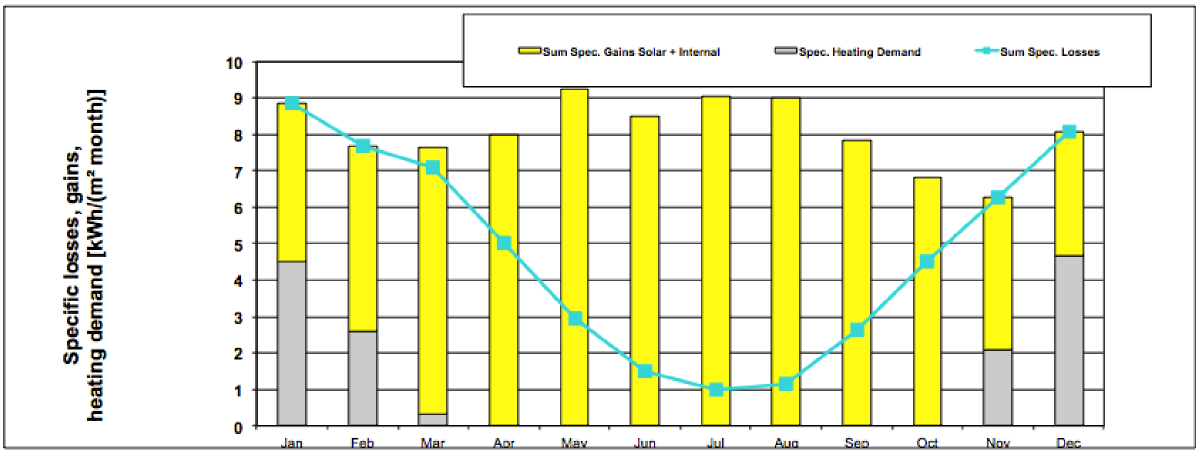


Figure 6.2.11.1. Specific losses, gains, heating demanc for each month. [51]

The Annual Heating Demand Q_H = **14 KWh/(m^{2}a) < 15 KWh/(m^{2}a)** → Requirement is met.

6.2.12. “Heating Load“ Worksheet

In this worksheet is checked the condition for using fresh air as heat source:

$$P_H \leq P_{supply,max}$$

P_H – The maximum heating load [W]
$P_{supply,max}$ – The maximum heating power [W]

$$1697 \text{ W} \geq 932 \text{ W}$$

The maximum heating load exceeds the allowed $P_{supply,max}$ value, so the Supply Air Heating is not sufficient and the additional system is necessary. Therefore, in the „PE Value“ Worksheet the additional source of heat was entered with the use of Boiler.

6.2.13. “Summer“ Worksheet

Passive houses should provide a high thermal comfort, not only in winter but also in summer. Comfortable temperatures in summer for Passive Houses are not much more difficult to obtain than in other buildings. The highly insulated envelope makes, that in general is easy to keep the building cool during the summer season.

For the summer interior temperature, the greatest impact have: window size, orientation, shading, ventilation, interior heat sources and climatic region.

Entries input in this Worksheet are as follows:

- Spec. Capacity: 132 Wh/(m^{2}K) for the Mixed massive enclosing wall surfaces
- Overheating limit: 25℃ (default value)
- Mechanical Ventilation Summer: 0.45 1/h

- Air Change Rate by Natural (Windows & Leakage) or Exhaust-Only Mechanical Ventilation, Summer: 0.23 1/h
- Additional Summer Ventilation for Cooling: Window Night Ventilation, Manual
- Corresponding Air Change Rate: 0.16 1/h
- Minimum Acceptable Indoor Temperature: 22 °C

The measure of summer comfort is defined as the Frequency of Overheating:

$\boldsymbol{h_{\theta/\theta max}}$**= 6,8%** at the overheating limit $\theta_{max} = 25$ °C

The frequency over 25 °C does not exceed 10%, so additional measures to protect against summer heat waves are not necessary

6.2.14. “Shading-S“ Worksheet

This Worksheet calculates the auxiliary shading factors as shading by a neighbouring row of houses, shading by window reveals and shading by overhanging horizontal elements above the window.

The reduction factors for typical shading devices 18599-2 are shown in Figure 6.2.14.1.

Type of Shading Device	exterior position	interior position
Blinds, vertical lamellas:	0.06	0.7
Blinds, lamellas 45°:	0.1	0.75
Roller blinds / marquees, white	0.24	0.6
Roller blinds / marquees, grey	0.12	0.8
Foil	-	0.6

Figure 6.2.14.1. Reduction factors for typical shading devices. [51]

The reduction factor to be entered has to be calculated according to the formula:

$$z_{effective} = 0,3 + 0,7 \cdot z$$

In the building were designed blinds for the southern windows. Reduction factor for temporary sun protection for the southern windows, is calculated due to the formula:

$$z_{effective} = 0{,}3 + 0{,}7 \cdot 0{,}7 = 0{,}79 \rightarrow \mathbf{79\%}$$

Summer shading factor for the particular orientation is shown in Table 6.2.14.2.

Table 6.2.14.2. Results from the „Shading-S“ Worksheet for the Summer shading factor r_s.

Orientation	Glazing Area [m^2]	Summer shading factor r_s
North	2,42	78%
East	2,79	79%
South	19,25	63%
West	2,42	79%
Horizontal	0,00	100%

6.2.15. “SummVent“ Worksheet

In the “SummVent“ Worksheet was defined the rate of Exchange through open windows which is a critical parameter for the summer indoor climate.

In the calculation of Summary Ventilation Distribution the windows shown in Table 6.2.15.1 were taken into account.

Table 6.2.15.1. Entries for the "SummVent" Worksheet.

Description	Day South	Day East	Day South	Night South	Night East
Fraction of Opening Duration	50%	50%	50%	70%	70%
Quantity	1	1	1	1	1
Clear Width	1,84	0,84	1,84	1,84	0,84
Clear Height	1,29	0,44	1,29	1,29	1,29
Cross Ventilation					
Clear Width			1	1	1
Clear Height			0,84	0,84	0,84
Quantity			1,29	1,29	1,29

Two of the windows on the southern and eastern elevations are opened during the 50% of the daytime. There is also obtained cross ventilation between the two windows on the northern and southern elevations, located at the same height. These windows are open at night by 70% of the nighttime.

The data entered in this Worksheet is as follows:

- Temperature Difference between Interior and Exterior for day time: 4 K for the windows used for air Exchange all day long
- Temperature Difference between Interior and Exterior for night time: 1 K for the windows used for air Exchange all night long
- Wind Velocity for day time: 1 m/second for the wind occurring during the hot summer periods
- Wind Velocity for night time: 0 m/second for the assumption there is no wind
- All windows are design as Tilting Windows with the Opening Width of 5 cm.

The results obtained in this Worksheet are as follows:

Table 6.2.15.2. Daily average air change rate for the Nighttime and Daytime Ventilation.

Description Ventilation Type	Daily Average Air Change Rate [1/h]
Nightime Window Ventilation	0,16
Daytime Window Ventilation	0,23

6.2.16. “Cooling“ Worksheet

The “Cooling“ Worksheet serves to calculate cooling demand. It means how much heat must be extracted from the house to obtain the comfortable climate inside the rooms.

However, for the Polish Climate Requirement for the Cooling demand is met with the wide margin, so no Cooling Units are needed for the Passive House in Polish Climate.

No data entry is needed in this worksheet.

6.2.17. “Cooling Units“ Worksheet

Since cooling is not considered in designed house, no data entry was done in this Worksheet.

6.2.18. “Cooling Load“ Worksheet

The calculation results in this Worksheet represents a daily average of the cooling capacity for the design day, taking into account energy balance of internal and solar loads, conduction and ventilation losses or gains for the design day.

Obtained in this Worksheet - the Daily Temperature Swing due to Solar Load = 2,8 K $\leq$ 3 K, so the requirement concerning daily temperature swing is fulfilled.

6.2.19. “DWH + Distribution“ Worksheet

„DWH + Distribution“ Worksheet calculates the heat losses of the distribution system for space heating and DHW.

In this worksheet can be also found a tool for calculation the heat loss coefficient Ψ for the distribution pipes.

The heat lost through the pipes, located within the thermal envelope, can act as an internal source, so therefore the part of the heat is use to reduce the annual heating demand.

In Table 6.2.19.1. are shown the data input for the „DWH + Distribution“ Worksheet, as well as based on them results for the Space Heat Distribution:

Table 6.2.19.1. Data entered for the Space Heat Distribution.

Space Heat Distribution	
Length of Distrubution Pipes L_H [m]	41,80
Temperature Heat Loss Coefficient per m Pipe Ψ [W/(mK)]	0,344
Temperature of the Room Through Which the Pipes Pass ϑ_X [°C]	20
Design Flow Temperature ϑ_{dist} [°C]	55.0
Design System heating load $P_{heating}$ [kW]	1.4
Flow Temperature Control	x
Design Return Temperature ϑ_R [°C]	45.0
Annual Heat Emission per m of Plumbing q^*_{HL} [kWh/(ma)]	14
Possible Utilization Factor of Released Heat η_G	59%
Annual Losses Q_{HL} [kWh/a]	242
Specif. Losses q_{HL} [kWh/(m^{2}a)]	2.3
Performance ratio of heat distribution $e_{a,HL}$	116%
Spec. Useful Heat [kWh/(m^{2}a)]	23.1

In the Passive House standards the domestic hot water demand for residential buildings amounts in 25 litres per person per day at 60 °C.

For DHW has been designed the Individual pipes, so without the constant pump-driven hot water circulation. The overall length of the individual pipes was counted as the sum of all sections from the beginning of the branch pipe to the tapping points.

In Table 6.2.19.2. the data input for the “DWH + Distribution“ Worksheet, as well as based on them results for the DHW Distribution and Storage are listed.

Table 6.2.19.2. Data entered for the DHW Distribution and Storage.

DHW Distribution and Storage	
Total Length of Individual Pipes L_U [m]	33.16
Exterior Pipe Diameter d_{U_Pipe} [m]	0.018
Heat loss per tap opening $q_{individual}$ [kWh/tap opening]	-0.1418
Amount of tap openings per year n_{Tap} [Tap openings per year]	4380
Annual Heat Loss q_U [kWh/a]	-621
Possible Utilization Factor of Released Heat $\eta_{G,U}$	36%
Annual Heat Loss of Individual Pipes Q_U [kWh/a]	-399
Performance ratio DHW-distribution + storage [%]	83.7
Total Heating Demand of DHW systém [kWh/a]	2053
Total Spec. Heating Demand of DHW System [kWh/(m^{2}a)]	19.4

6.2.20. “Solar DWH“ Worksheet

In this worksheet can be calculated the Solar contribution of a typical system for solar DHW generation.

The entries that were put for Solar Collector, taken from the manufacturer’s catalog are shown in Table 6.2.20.1.

Table 6.2.20.1. Parameters for the used Vacuum Tube Collector.

Vacuum Tube Collector	
Sollar Collector Area	4,24 m^2
Deviation from North	180 °
Angle of inclination from the horizontal	45 °
Height of the Collector Field	1,98 m
Additional Reduction Factor Shading	100%

The obtained in the „Solar DWH“ Worksheet“ results are:

- Estimated Solar Fraction of DHW Production: **76%**
- Solar Contribution to Useful Heat: **1570 kWh/a**

For the chosen Stratified Solar Storage, the parameters of this unit are shown in Table 6.2.20.2.

Table 6.2.20.2. Parameters for the used Stratified Solar Storage.

Stratified Solar Storage	
Total Storage Volume	391 litre
Volume Standby Part	117 litre
Volume Solar Part	274 litre
Specific Heat Losses Storage (total)	2,9 W/K
Typical Temperature DHW	55 °C
Storage Heat Losses (Standby Part)	27 W
Total Storage Heat Losses	112 W

In the „Solar DHW“ Worksheet were taken into account in the calculation for the solar thermal system contribution rate, such parameters as the heat losses in the solar circuit and the heat losses of the solar fraction of the DHW storage tank.

Obtained a graphical representation of the solar radiation, heating load, DHW generation, heating load covered by solar are shown in Figure 6.2.30.1.

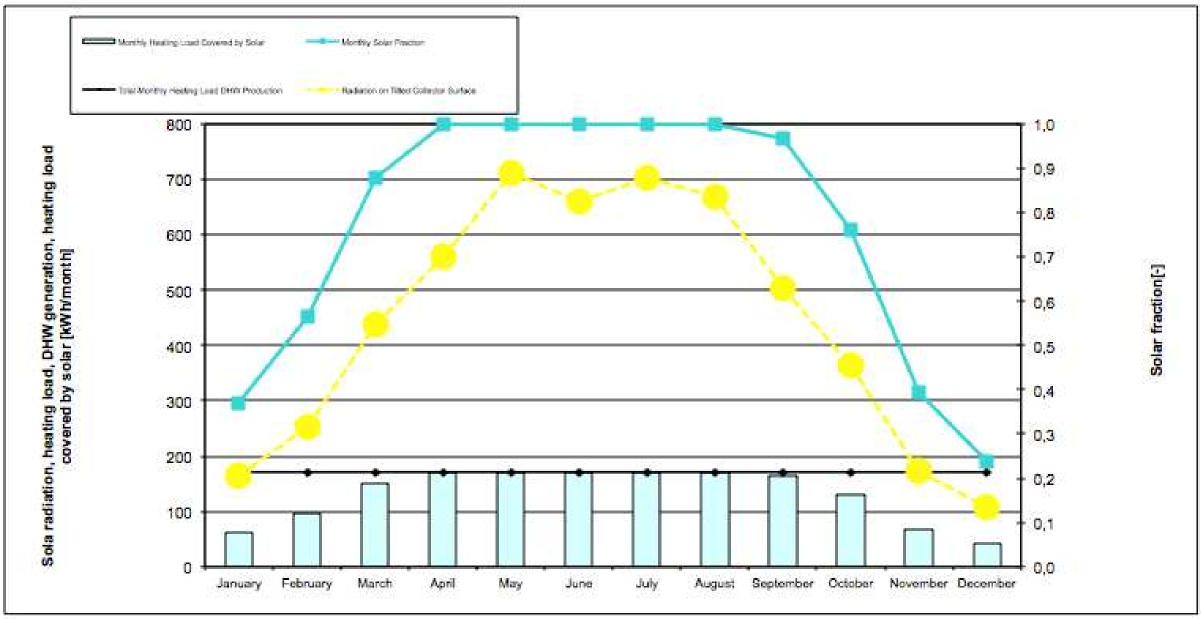


Figure 6.2.20.1. Graph of solar radiation, heating load, DHW generation and heating load covered by solar for each month. [51]

6.2.21. "Electricity" Worksheet

This Worksheet serves for the total energy demand calculations, which takes into consideration all of the energy services normally provided by electricity including auxiliary energy.

The electricity demand in Passive House should be maximally reduce to achieve the primary energy requirement for Passive House:

$$\mathbf{q} \leq \mathbf{120\ kWh}/(\mathbf{m^2 a})$$

For the services presented in this Worksheet the recommended maximum values for Specific Electricity and Energy Demand are given below as a function of the Treated Floor Area:

- Recommended Specific Electricity Demand: **18 kWh/(m²a)**
- Recommended Specific Primary Energy Demand for Electricity: **50 kWh/(m²a)**

There have been determined the electrical devices that are used, if they are located within the thermal envelope, and as well they are given Norm Demand for every device.

The obtained results in the Worksheet are as follows:

- Specific Electricity Demand: **17.2 kWh/(m^{2}a) $\leq$ 18 kWh/(m^{2}a)**
- Specific Primary Energy Demand for Electricity: **52.7 kWh/(m^{2}a) $\leq$50 kWh/(m^{2}a)**

6.2.22. “Auxiliary Electricity“ Worksheet

This worksheet describes all electrical consumption, that serves for running and controlling the building’s mechanical systems, such as: heating, ventilation, solar thermal systems and DHW systems.
It was decided that the auxiliary electricity will be spent for: Winter Ventilation, Summer Ventilation, Defroster HX, Storage Load Pump DHW, DHW Boiler, Solar. All the appliances are located within the thermal envelope.

The obtained results in this Worksheet are as follows:

- Specific Electricity Demand: **5.3 kWh/(m^{2}a)**
- Specific Primary Energy Demand for Electricity: **13.7 kWh/(m^{2}a)**

6.2.23. “Primary Energy Value“ Worksheet

The specific primary energy demand describes the amount of non-renewable primary energy, which can be calculated in this worksheet, including combinations of different types of system, as:

- Electric space heating and electric DHW boilers
- Heat pumps
- Passive House comapact units with electric heat pump
- Natural gas, fuel oil or wood boilers
- District heat
- Other heating systems.

In this worksheet the user combine heating systems by stating the percentage of space heat provided by each systems.

It was established, that the Fraction of DHW Demand and Space Heating Demand will be cover in 100% by the boiler.

Obtained values in this Worksheet for the Heating, Cooling, DHW, Auxiliary and Household Electricity are as following:

- Total PE Value: **82.2 kWh/(m^{2}a)**
- Total Emissions CO_2 - Equivalent: **20.2 kWh/(m^{2}a)**

the primary energy requirement for Passive House: $\mathbf{q} \leq \mathbf{120\ kWh}/(\mathbf{m^2 a})$ is fulfilled.

6.2.24. "Boiler" Worksheet

This Worksheet serves for determine the boiler performance ratio for the residual space heating and DHW supply.

The boiler type that was selected is Low Temperature Boiler Gas.

Utilisation Factor Heat Generator DHW & Heating obtained in this Worksheet amounts in **71%.**

6.2.25. "Climate Data" Worksheet

This worksheet contains of the data for the calculation of heating demand and cooling load of the building. Climate data may be chosen from the list with the available locations. The Regional Climate Data used for calculation in PHPP is „PL-Strefa II (Poznan/Pila)." **(**according to EN 13790).

As a results is obtained the data for the selected zone.
The Solar radiation dependent of parts of the world is presented graphically in Figure 6.2.25.1.

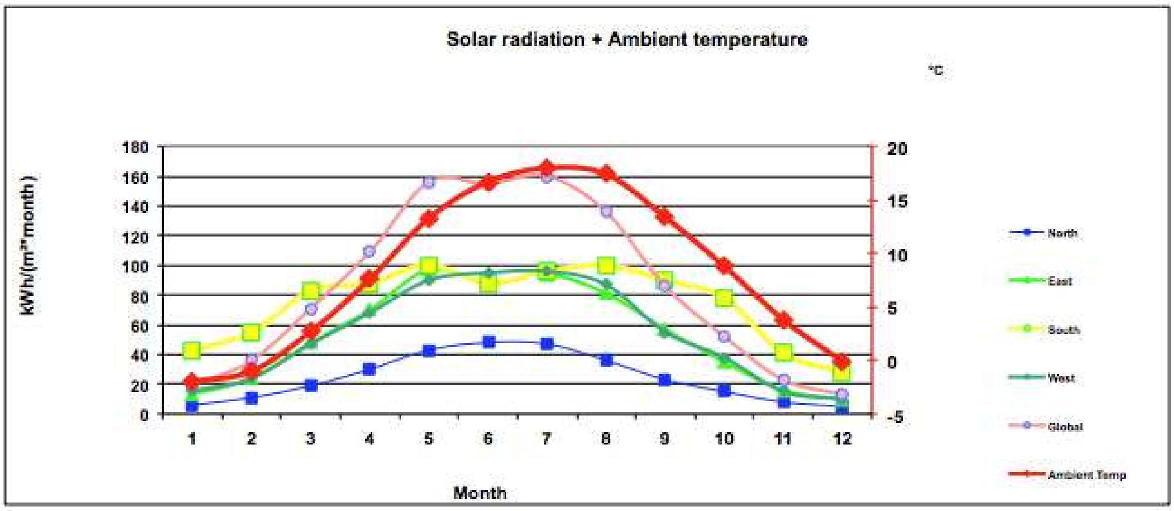


Figure 6.2.25.1. Solar radiation and Ambient temperature depending of the world directions. [51]

Chapter 7

Calculations for the standard house with Passive House Planning Package (PHPP)

7. Calculations for the standard house with Passive House Planning Package (PHPP)

7.1. Introduction

In this part of work will be performed calculations for the Standard House located in Polish Climate according to the PHPP Software

7.2. Worksheets description

7.2.1. “Verification“ Worksheet

In this Worksheet the all data, except the set point temperature, was entered the same as for the Passive House (see p. 6.2.1.).

The default value for interior design temperature in PHPP is 20℃. However, to make the calculations the most comparable with the calculations according to the EN ISO 13790, the set point temperature was calculated according to the following formula (EN ISO 13790):

$$\theta_{int,H,set} = \frac{(2{,}67\mathrm{m}^2+9.02\mathrm{m}^2)\times 24℃+\left(106{,}1\mathrm{m}^2-(2{,}67\mathrm{m}^2+9.02\mathrm{m}^2)\right)\times 20℃}{106{,}1\mathrm{m}^2} = 20{,}441℃$$

where:

2.67 m^2 and 4.50m^2 - areas of bathrooms;

106.1 m^2 - treated floor area (TFA);

20.441℃ - final set-point temperature for the whol e building

For bathroom and WC the temperature that was assumed is 24 ℃ and for all other rooms in the building the temperature is 20 ° C.

Thus, the same value of 20.441 ℃ was introduced in the calculations according to the EN ISO 13790 and calculations performed for the Standard House in the PHPP.

The most important values we receive in this Worksheet are as show in Table 7.2.1.1.:

Table 7.2.1.1. Results obtained in the “Verification” Worksheet

	Obtained Value	Requirement for Passive House
Annual Heating Demand [kWh/(m^{2}a)]	29.08	15
Heating load [W/m^2]	19.00	10
Frequency of overheating (>25°) [%]	26.30	10
Space heating and cooling, dehumidification, DHW, Auxiliary Electricity and household electricity [kWh/(m^{2}a)]	-	120
Pressurization test result n_{50} [1/h]	0.60	0.6

7.2.2. “Areas“ Worksheet

The same data related to building thermal envelope, as for calculations for the Passive House (p.6.2.2), was entered in this Worksheet.

7.2.3. “U-List“ Worksheet

The same summary with the description of the building, the overall thickness and the U-value as for calculations for the Passive House (p.6.2.3) was obtained in this Worksheet.

7.2.4. “U-Values“

The same data for calculation the overall transfer coefficients as for the Passive House (p.6.2.4) was entered in this Worksheet.

7.2.5. “Ground“ Worksheet

The same data for heat losses of below-ground building elements, as for the for the Passive House (p.6.2.5), was entered in this Worksheet.

The results for this Worksheet are as follows:

Table 7.2.5.1. Results for the “Ground” Worksheet.

Ground reduction for “Annual Heating Demand“ Worksheet	0,65
Design Temperature for “Heating Load“ Worksheet	6,7

Monthly Average Ground Temperatures for Monthly Method which was also obtained in this Worksheet is presented in Table 7.2.5.2.

Table 7.2.5.2. Monthly Average Ground Temperatures for Monthly Method.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average Value
Winter	7,8	6,7	6,8	8,0	10,0	12,4	14,4	15,5	15,4	14,2	12,1	9,8	11,1
Summer	8,5	7,4	7,5	8,7	10,8	13,1	15,1	16,2	16,1	14,9	12,8	10,5	11,8

7.2.6. “Windows“ Worksheet

The same data for the applied Windows as for the Passive House (p.6.2.6) was entered in this Worksheet.

Important results from this Worksheet, concerning the annual transmission losses through the windows and heat gains from solar radiation are presented in Table 7.2.6.2.

Table 7.2.6.2. Transmissions losses and heat gains for the word directions.

Window area orientation	Transmission losses [kWh]	Heat gains [kWh]
North	186	181
East	201	253
South	1086	2478
West	186	210
Σ	1659	3121

7.2.7. “WinType“ Worksheet

The same data for the applied window frame and window glazing as for the Passive House (p.6.2.7) was entered in this Worksheet.

7.2.8. “Shading“ Worksheet

The same data for the calculation of the total Shading Factor, as for the Passive House (p.6.2.8) was entered in this Worksheet.

Also the same results for the total Shading Factor, as for the Passive House (p.6.2.8) were obtained in this Worksheet.

7.2.9. “Ventilation“ Worksheet

Data entered in this Worksheet:

- Type of ventilation system: Pure extract air (for standard building)
- Wind protection coefficient *e*: 0.07 (for a building in a suburban development with several sides exposed to wind action)
- Wind protection coefficient *f*: 15 (for a building with several sides exposed)
- Air Change Rate at Press. Test: n_{50} = 0.6h^{-1} (the maximum value for the air change rate at 50Pa pressure difference)
- Net Air Volume for Press. Test: 531 m^3 (the volume of heated space)
- Supply air per person: 30 m^3/h (default value)

No ventilation unit with heat recovery was selected for the standard house.

The values for the extract from the rooms air are the same as for the Passive House (p.6.2.9) and are shown in Table 6.2.9.1.

The following results are obtained in this Worksheet:

- Average air flow rate: **108 m^3/h**
- Average air change rate: **0,41 1/h**

No more data was entered in this Worksheet for the standard house case.

7.2.10. "Annual Heating Demand" Worksheet

In this section there are summarized all of the heat losses and gains.

The obtained graph chart for the Heating energy balance for the Standard House, showing the Heat flows in two columns, which are divided into parts that correspond to different fractions of total heat losses and heat gains, is presented in Figure 7.2.10.2.

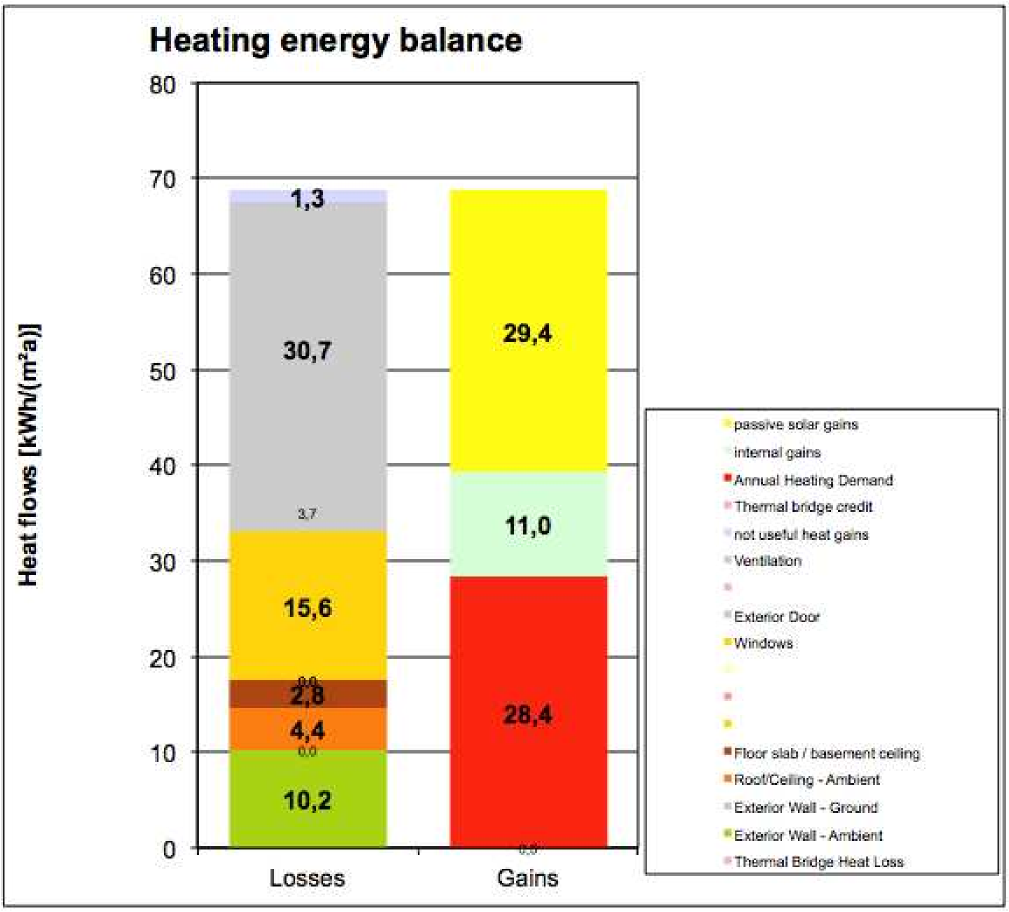


Figure 7.2.10.1. Heating energy balance. [51]

The Annual Heating Demand Q_H = **28 KWh/(m^{2}a)** > **15 KWh/(m^{2}a)** → Requirement is not met for the standard building.

7.2.11. "Monthly Method" Worksheet

In the „Monthly Method" Worksheet the energy balance is calculating using an energy balance for every month of the year. All the energy data are retrieved from the „Annual Heating Demand" worksheet.

In this worksheet there is graphically illustrated monthly heating demand, specific gains and losses:

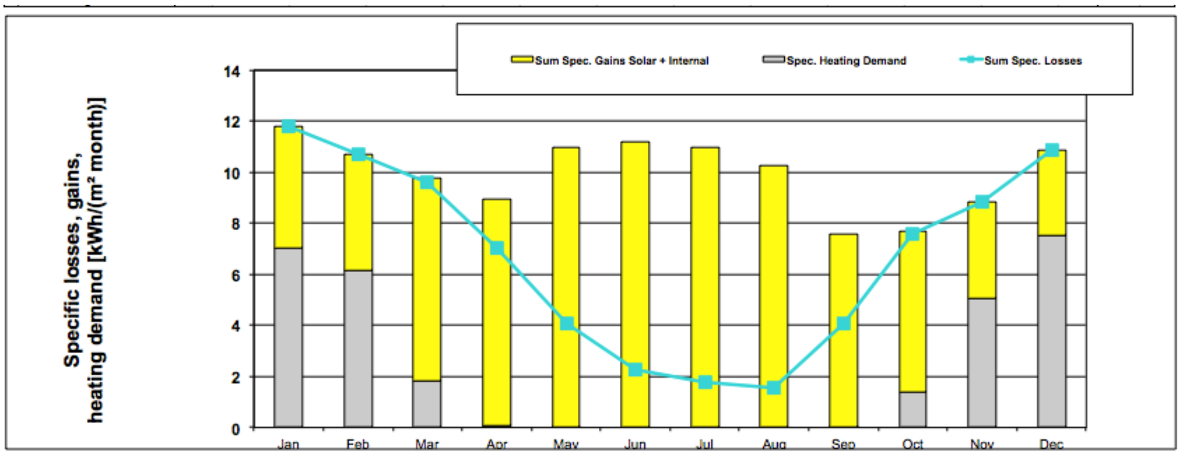


Figure 7.2.11.1. Specific losses, gains, heating demanc for each month. [51]

The Annual Heating Demand Q_H = **29 KWh/(m^{2}a)** > **15 KWh/(m^{2}a)** → Requirement is not met for the standard building.

7.2.12. "Climate Data" Worksheet

This worksheet contains the data for the calculation of heating demand and cooling load of the building. Climate data for the standard house, the same as for the calculations according to EN 13790 was taken from the meteorological station in Poznan.

The Solar radiation dependent of parts of the world is presented graphically in Figure 7.2.12.1.

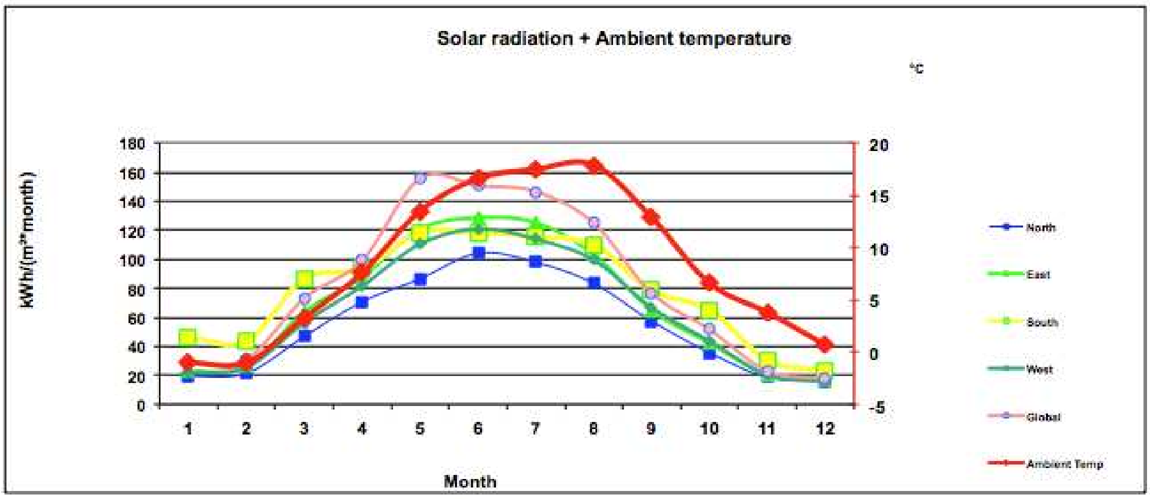


Figure 7.2.12.1.Solar radiation and Ambient temperature depending of the world's directions.[51]

Chapter 8

Calculations for the standard house according to EN 13790

8. Calculations for the standard house according to the EN 13790

8.1. Introduction

In this chapter of the dissertation there are presented calculation for the designed dwelling according to the EN ISO 13790 “Energy performance of buildings – Calculation of energy use for space heating and cooling”.
The calculations were performed for the same object as previously calculated in the PHPP.

The purpose of the calculation according to the EN ISO 13790 is to compare the energy calculations for a passive house calculated in the PHPP and a standard house in the Polish climate, however, containing a number of solutions that are used in the designed passive house, such as: partitions design solutions, large thickness of thermal insulation, minimization of thermal bridges, the use of doors and windows with a very high thermal insulation.

As calculations According to EN ISO 13790 has been, as in the case of PHPP calculation, carried out for the house located in Polish climate, it was decided not to calculate an annual cooling demand for this building. The value for cooling demand is negligible compared to the heating demand, therefore, it was decided that for the heating period will be taken into account 9 months, from September to May.

Calculations were performed in the MATHCAD program. In this chapter will be presented formulas according to which the calculations were performed.

8.2. Description of the calculation according to EN 13790

The diagram below shows the scheme for calculations performed in accordance with EN ISO 13790.

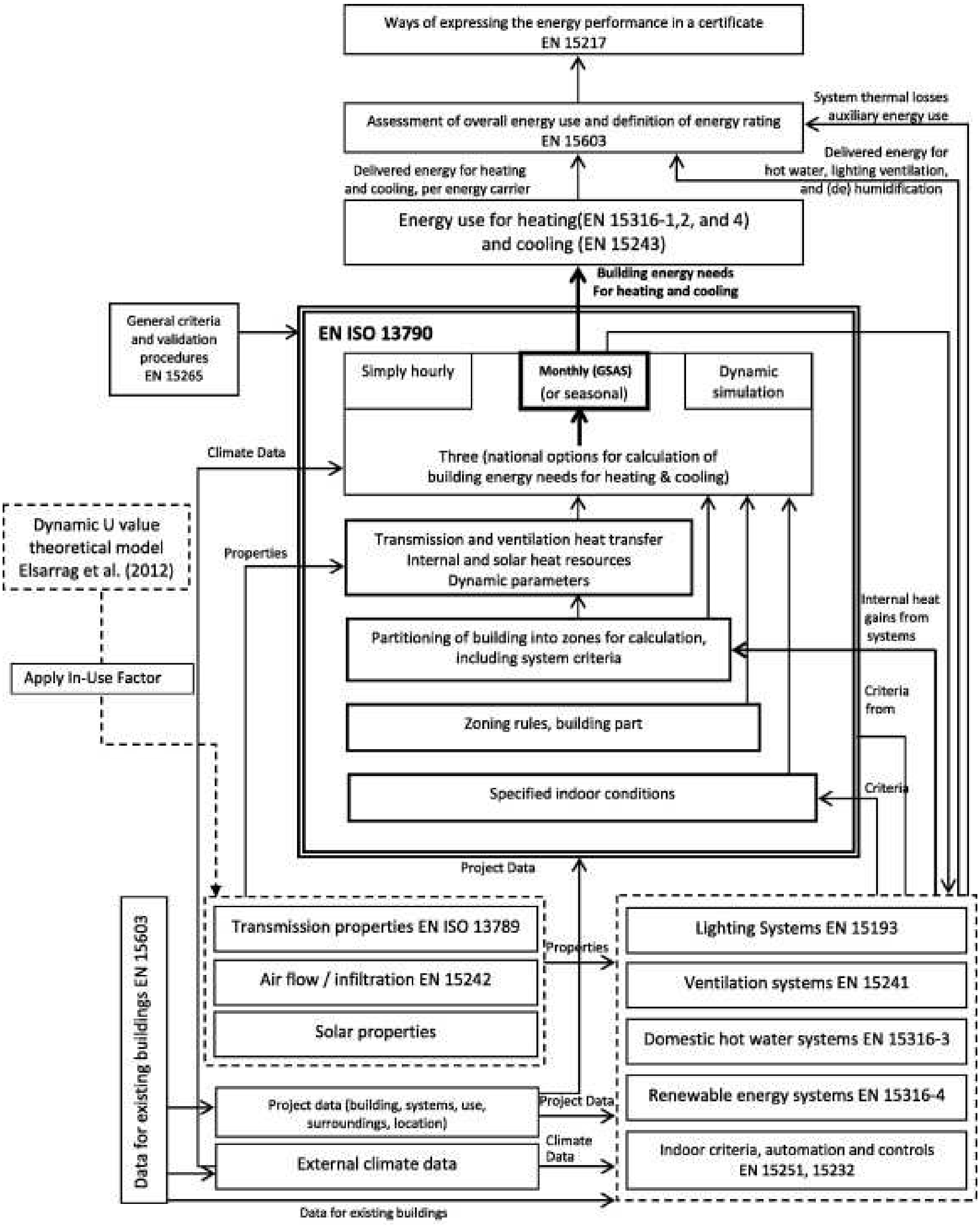


Figure 8.2.1. Chart for calculations according to EN 13790. [69]

8.2.1. Energy need for heating

The building energy demand for space heating is given by the value of total heat transfer for the heating mode reduced by the multiplication of total heat gains for the heating mode and utilization factor.

To obtain the energy needed for heating, calculations for the total heat transfer for the heating mode, total heat gains for the heating mode and utilization factor were performed to formulas presented below.

8.2.1.1. Heat transfer by transmission

The equation to calculate the heat transfer by transmission is as follows:

$$Q_{tr} = H_{tr,adj} \times \left(\theta_{int,set,H} - \theta_e\right) \times t \quad [\mathrm{J}]$$

where:

$H_{tr,adj}$ – overall heat transfer coefficient by transmission $[\frac{\mathrm{W}}{\mathrm{K}}]$

$\theta_{int,set,H}$ – set-point temperature of the building zone for heating, [K]

θ_e – temperature of external environment [K]

t – duration of the calculation step [Ms]

8.2.1.2. Transmission heat transfer coefficient for opaque thermal envelope

The equation to calculate the transmission heat transfer coefficient is as follows:

$$H_{tr,adj} = H_D + H_g + H_U + H_A \quad [\frac{\mathrm{W}}{\mathrm{K}}]$$

H_D - direct heat transfer coefficient by transmission to the external environment $[\frac{\mathrm{W}}{\mathrm{K}}]$

H_g - heat transfer coefficient by transmission to the ground $[\frac{\mathrm{W}}{\mathrm{K}}]$

H_U - heat transfer coefficient by transmission through unconditioned spaces $[\frac{\mathrm{W}}{\mathrm{K}}]$

H_A - heat transfer coefficient by transmission to adjacent buildings $[\frac{\mathrm{W}}{\mathrm{K}}]$

The all four specific heat transfer coefficients described above are calculated according to the following formula:

$$H_x = b_{tr,x} \times [\Sigma_i A_i U_i + \Sigma_k l_k \psi_k + \Sigma_j \chi_j] \quad [\frac{\mathrm{W}}{\mathrm{K}}]$$

where:

A_i – area of element i of the building envelope [m^2]

U_i – thermal transmittance of element i of the building envelope $[\frac{\mathrm{W}}{\mathrm{m^2K}}]$

l_k – length of the linear thermal bridge k [m]

ψ_k – linear thermal transmittance of thermal bridge k $[\frac{\mathrm{W}}{\mathrm{m\ K}}]$

χ_j – point thermal transmittance of point thermal bridge j $[\frac{\mathrm{W}}{\mathrm{K}}]$

$b_{tr,x}$ – adjustment factor [-]

All the specific calculations for the transmission heat transfer coefficient for opaque thermal envelope can be found in Section 2.2.

8.2.1.3. Transmission heat transfer coefficient through thermal bridges

Calculations for the linear thermal bridges were performed in THERM and presented already in Section 5.3.2. The summary for all of the linear thermal bridges and linear thermal transmittances that were used in calculations are listed in Table 8.2.1.3.1.

Table 8.2.1.3.1. Linear thermal bridges with heat transfer coefficients.

Linear thermal bridge	Linear thermal transmittance Ψ $[\frac{\mathrm{W}}{\mathrm{m\ K}}]$
Exterior wall corner	$-0{,}054$
Connection of the exterior wall with the floor slab	$-0{,}092$
Connection of the exterior wall with the roof slab	$-0{,}021$
Connection of the exterior wall with the concrete beam	$0{,}023$
Connection of the exterior wall with the staircase slab	$0{,}001$
Connection of the window with the exterior wall	0.021

8.2.1.4. Total value of heat transfer by transmission

The annual value of heat transfer by transmission obtained according to EN 13790 is as follows:

$$Q_{tr} = 1.396 \times 10^{10}\mathrm{J} = 36.548\ \mathrm{kWh/m^2}$$

All the specific calculations for the total value of heat transfer by transmission can be found in the Annex 2.3.

8.2.1.5. Heat transfer by ventilation

The equation to calculate the heat transfer by ventilation is as follows:

$$Q_{ve} = H_{ve,adj} \times \left(\theta_{int,set,H} - \theta_e\right) \times t$$

where:

$H_{ve,adj}$ – overall heat transfer coefficient by ventilation $[\frac{\mathrm{W}}{\mathrm{K}}]$

$\theta_{int,set,H}$ – set-point temperature of the building zone for heating [K]

θ_e – temperature of external environment [K]

t – duration of the calculation step [Ms]

8.2.1.6. Heat transfer coefficient by ventilation

The equation to calculate heat transfer coefficient by ventilation is as follows:

$$H_{ve,adj} = \rho_a c_a (\Sigma_k b_{ve,k} q_{ve,k,mn})$$

where:

$\rho_a c_a$ – heat capacity of air per volume, $[\frac{\mathrm{J}}{\mathrm{m^3K}}]$

$q_{ve,k,mn}$ - time-average airflow rate of air flow element k $[\frac{\mathrm{m^3}}{\mathrm{s}}]$

$b_{ve,k}$ – temperature adjustment factor for air flow element [-]

8.2.1.7. Time-average airflow rates

The values for the time-average airflow rates for supplied and extracted air have been already presented in the Section 5, in Table 5.6.2.1. The values for the calculation in accordance with EN 13790 are the same as those in PHPP to make these calculations the most comparable.

8.2.1.8. Total value of heat transfer by ventilation

The obtained annual value of heat transfer by ventilation is as follows:

$$Q_{ve} = 1.678 \times 10^{10}\mathrm{J} = 43.931\ \mathrm{kWh/m^2}$$

All the specific calculations for the Total value of heat transfer by ventilation can be found in the Annex 2.4.

8.2.2. Total heat gains

The building total heat gains are the sum of internal heat gains and solar heat gains. To calculate the total heat gains there were performed calculations according to presented below formulas.

8.2.2.1. Internal heat gains

Internal heat gains that were considered in this section are metabolic heat from occupants and heat dissipated from appliances and lighting devices.

8.2.2.2. Internal heat flow rate from occupants and appliances

The values for the internal heat flow rate from occupants and appliances according to the EN ISO 13790 were assumed as:

- For the living room and kitchen: $9\ \frac{\mathrm{W}}{\mathrm{K}}$
- For bedrooms : $3\ \frac{\mathrm{W}}{\mathrm{K}}$

The obtained annual value of heat flow rate from the occupants and appliances is as follows:

$$\theta_{int,Oc} = 8.218 \times 10^{9}\mathrm{J} = 21.515\ \mathrm{kWh/m^{2}}$$

All the specific calculations for the internal heat flow rate from occupants and appliances can be found in the Annex 2.5.

8.2.2.3. Internal heat flow rate from lighting

The equation to calculate heat transfer by ventilation is as follows:

$$\phi_{int,L} = N \times [\beta + (1-\beta) \times k_0] \times \varphi$$

where:

N – total power of the lighting for the house [W]; (it was assumed as 40 bulbs, 40 watts each)

β – coefficient depended both on: type of lamp fixing to the wall or ceiling and type of the lamp; (it was assumed freely suspended, fluorescent lamps) [-]

k_0 – coefficient related to the accumulation of the partitions, for most of the buildings (it was assumed as 1.0) [-]

φ – coefficient of lighting simultaneously (it was assumed separately for each month) [-].

Table 8.2.2.3.1. Lighting simultaneously coefficient for each month.

Lighting simultaneously coefficient	Month	Value
φ_1	January	0.5
φ_2	February	0.5
φ_3	March	0.4
φ_4	April	0.3
φ_5	May	0.3
φ_9	September	0.3
φ_{10}	October	0.4
φ_{11}	November	0.4
φ_{12}	December	0.5

The obtained annual value of heat flow rate from lighting is as follows:

$$Q_{int,Oc} = 1.508 \times 10^{10}\mathrm{J} = 39.481\ \mathrm{kWh/m^2}$$

All the specific calculations for the internal heat flow rate from lighting can be found in the Annex 2.6 and Annex 2.7.

8.2.2.4. Solar heat gains

The Solar heat gains were calculated by the following equation:

$$Q_{sol} = \left(\sum_k \phi_{sol,mn,k}\right) \times t + \left(\sum_k (1 - b_{tr,l}) \times \phi_{sol,mn,u,l}\right) \times t$$

where:

$b_{tr,l}$ – adjustment factor for the adjacent unconditioned space with internal heat source l [-]

$\phi_{sol,mn,k}$ – time-average heat flow rate from solar heat source k [W]

$\phi_{sol,mn,u,l}$ - time-average heat flow rate from solar heat source l in the adjacent unconditioned space [W]

t – timespan for each month [Ms]

8.2.2.5. Effective solar collecting area of glazed elements

The effective solar collecting area of glazed elements was calculated by the following equation:

$$A_{sol,w} = F_{sh,gl} \times g_{gl} \times (1 - F_F) \times A_{w,p}$$

where:

$F_{sh,gl}$ – shading reduction factor for movable provisions [-];

g_{gl} – coefficient of total solar energy transmittance of the transparent part of the element [-]

F_F – frame area fraction [-]

$A_{w,p}$ – overall projected area of the glazed element [m^2]

8.2.2.6. Solar gains through the glazed elements

The solar gains through the glazed elements were calculated by the following equation:

$$\phi_{sol,k} = F_{sh,ob,k} A_{sol,k} I_{sol,k} - F_{r,k} \phi_{r,k}$$

where:

$F_{sh,ob,k}$ – shading reduction factor for the external obstacles [-]

$A_{sol,k}$ – effective collecting area [m^2]

$I_{sol,k}$ – solar irradiance [$\frac{\mathrm{W}}{\mathrm{m}^2}$]

$F_{r,k}$ – form factor between the building element and the sky [-]

$\phi_{r,k}$ – extra heat flow due to thermal radiation to the sky from building element [W] . This value was calculated from the following equation:

$$\phi_r = R_{se} \times U_C \times A_C \times h_r \times \Delta\theta_{er}$$

where:

R_{se} – external surface heat resistance of the element [$\frac{\mathrm{m^2K}}{\mathrm{W}}$]

U_C – thermal transmittance of the element, [$\frac{\mathrm{W}}{\mathrm{m^2K}}$]

A_C - projected area of the element [m^2]

h_r - external radiative heat transfer coefficient [$\frac{\mathrm{W}}{\mathrm{m^2K}}$]

$\Delta\theta_{er}$ – average difference between the external air temperature and the apparent sky temperature [℃]

8.2.2.7. Total solar heat gains through the glazed elements

The obtained total solar heat gains through the glazed elements is as follows:

$$Q_{sol,w,TOTAL} = 1.657 \times 10^{10}\mathrm{J} = 43.373\ \mathrm{kWh/m^2}$$

All the specific calculations for the total solar heat gains through the glazed elements can be found in the Annex 2.8 and Annex 2.9.

8.2.2.8. Collecting area of opaque building elements

The collecting area of opaque building elements was calculated by the following equation:

$$A_{sol,W} = \alpha_{S,c} \times R_{se} \times U_C \times A_C$$

where:

$\alpha_{S,c}$ – absorption coefficient for solar radiation of the opaque part (assumed as 0.7 for the exterior walls and 0.9 for the roof [-]

R_{se} – external surface heat resistance (assumed as 0.04 $\frac{m^2K}{W}$), [$\frac{m^2K}{W}$]

U_C – thermal transmittance of the opaque part (assumed 0.256 $\frac{W}{m^2K}$ for the walls and 0.209 $\frac{W}{m^2K}$ for the roof), $[\frac{W}{m^2K}]$

A_C - projected area of the opaque part [m^2]

8.2.2.9. Total solar heat gains through the opaque building elements

The obtained annual value of solar heat gains through the opaque building elements (walls and roof) is as follows:

$$Q_{sol.W.r} = 1.627 \times 10^9 \mathrm{J} = 4.26\ \mathrm{kWh/m^2}$$

All the specific calculations for the total solar heat gains through the opaque building elements can be found in the 2.10 and Annex 2.11.

Moreover, presented the monthly and annual solar heat gains through the opaque building elements can be found in the Annex 2.12 and the monthly and annual total heat gains can be found in Annex 2.13.

8.2.3. Dynamic parameters

The gain utilization factors for heating were calculated with the use of the following equations:

if $\gamma_H > 0\ and\ \gamma_H \neq 0$ $\qquad \eta_{H,gn} = \frac{1-\gamma_H{}^{a_H}}{1-\gamma_H{}^{a_H+1}}$

if $\gamma_H = 1$ $\qquad \eta_{H,gn} = \frac{a_H}{a_H+1}$

if $\gamma_H < 0$ $\qquad \eta_{H,gn} = \frac{1}{\gamma_H}$

where:

γ_H - heat-balance ratio, given by a the equation: $\gamma_H = \frac{Q_{H,gn}}{Q_{H,ht}}$ [-]

a_H – numerical parameter, given by the equation: $a_H = a_{H,0+} \frac{\tau}{\tau_{H,0}}$

where:

$a_{H,0}$ – numerical parameter [-]

τ – time constant [h]

$\tau_{H,0}$ – reference time constant [h]

All the specific calculations for the dynamic parameters can be found in the Annex 2.14.

8.2.4. Annual energy demand for heating

The obtained annual energy demand for heating is as follows:

$$Q_{H,nd} = 1.257 \times 10^{10}\mathrm{J} = 3.492 \times 10^{4}\mathrm{kWh} = 32.915\frac{\mathrm{kWh}}{\mathrm{m^2a}}$$

All the specific calculations for the Annual energy demand for heating can be found in the Annex 2.15.

Chapter 9

Comparison between obtained results

9. Comparison between obtained results

In Chapter 7 and Chapter 8 calculations with the use of PHPP Software and MATHCAD have been done. The purpose of performing these calculations was to compare the results obtained for the standard house located in Polish Climate in accordance to EN ISO 13790 “Energy performance of buildings – Calculation of energy use for space heating and cooling” and with the use of the PHPP Software.

The compared building is not passive, due to the impossibility of calculation such building according to EN ISO 13790 and what follows – comparison with the results from PHPP. Therefore, it was decided to calculate the standard building, however with many elements characteristic for the passive building. The most important applied passive solutions are: partitions with a thick layer of thermal insulation and very low thermal transmittance, paying a careful attention to minimize heat loss through thermal bridges and the use of high quality windows and doors with very high thermal insulation. Calculations according to EN ISO 13790 does not take into account such important element for passive building as heat recovery exchanger. Also in these calculations are not taken into account such issues as: heat flow connected with the domestic heat water distribution, use of the solar panels, electric home appliances, cross-ventilation use for the summer ventilation. Therefore, the data for these elements were also not included in the case of PHPP calculations, to make the calculations for the standard house the most comparable.

In Table 9.1. and Figure 9.1. are presented results of calculations for heat losses and gains with the use of different approaches

Table 9.1. Comparison for heat losses and gains obtained with the use of different approaches.

		Standard House EN 13790 $[\frac{\text{kWh}}{\text{m}^2}]$	Standard House PHPP Annual Method $[\frac{\text{kWh}}{\text{m}^2}]$	Standard House PHPP Monthly Method $[\frac{\text{kWh}}{\text{m}^2}]$
Heat losses	Transmission	36.55	36.80	38.40
	Ventilation	43.93	30.70	32.00
Heat gains	Transmission	43.37	29.40	34.90
	Ventilation	4.26	11.00	12.20
Annual Heating Demand		**32.92**	**27.19**	**28.06**

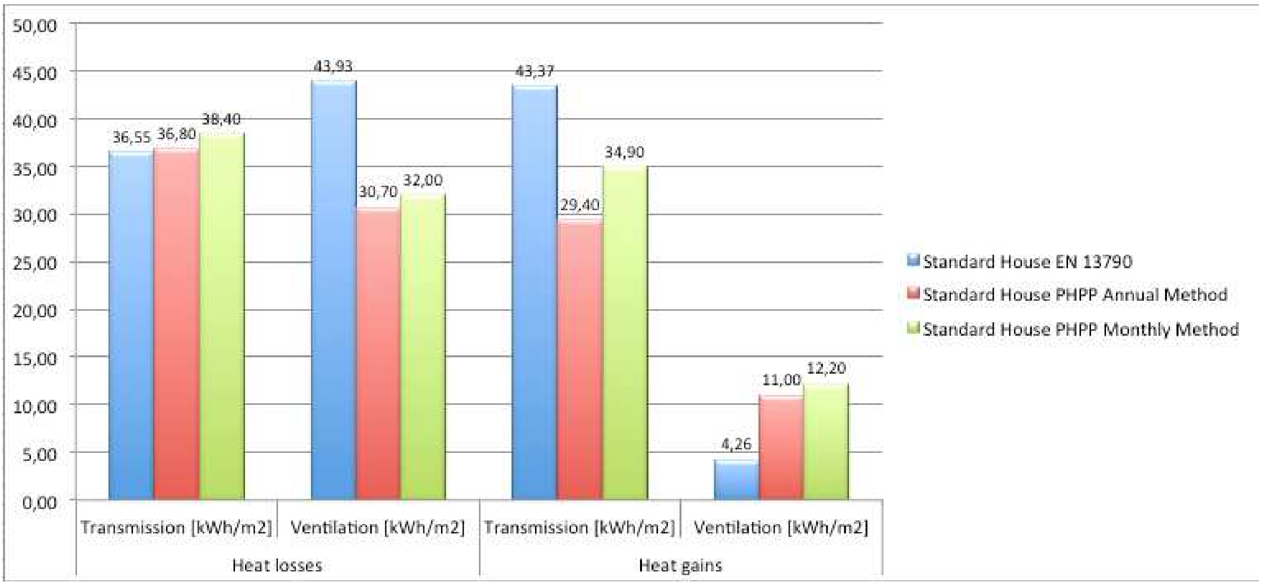


Figure 9.1. Comparison for heat losses and gains obtained with the use of different approaches.

As it can be clearly seen on the above presented results of comparison between EN 13790 and PHPP calculations, the biggest difference occurs for losses connected with heat ventilation, where the obtained value according to PHPP Annual method is 30.70 kWh/m^2, while for calculations according to EN 13790 the obtained value amounts in 43.93 kWh/m^2.

The closest and most comparable results are obtained in the case of comparison of the heat losses connected with transmission, where the differences between the EN 13790 and PHPP method are less than 5%.

Chapter 10

Conclusions and future perspectives

10. Conclusions and future perspectives

10.1. Conclusions

First of all, due to the performed calculations for the designed passive building, it can be presented that implementing the basic principles of passive house standard in construction by using appropriate solutions and design systems and components can be easily provided. The most important obtained results for the Passive house and the requirements which has to be met are listed in Table 10.1.

Table 10.1. Results and requirements for the Passive building.

	Result	Requirement for Passive House
Annual Heating Demand	14.17 kWh/(m^2a)	15 kWh/(m^2a)
Heating load	16 W/m^2	10 W/m^2
Frequency of overheating (>25°)	6.8 %	10 %
Space heating and cooling, dehumidification, DHW, Auxiliary Electricity and household electricity	82 kWh/(m^2a)	120 kWh/(m^2a)
Pressurization test result n_{50}	0.6 1/h	0.6 1/h

The obtained value for Annual heating demand is equal to 14.17 kWh/(m^2a). It meets the requirement for the passive buildings - 15 kWh/(m^2a). This condition has been fulfilled mainly by the application of a thick thermal insulation layer, appropriate windows and doors certificated by the Passive House Institute, minimization of heat losses through the thermal bridges and the use of highly efficient heat recovery exchanger.

The second part of calculations in this dissertation focused on comparison of Annual Heating Demand for the results obtained according to EN 13790 and Passive house standard.

The results for obtained Annual Heating Demand are as follows:

- EN 13790 – 32,90 kWh/m^2
- PHPP Annual Method – 27,19 kWh/m^2
- PHPP Monthly Method – 28,06 kWh/m^2

Obtained values for Annual Heating Demand are presented graphically in the Figure 10.1.

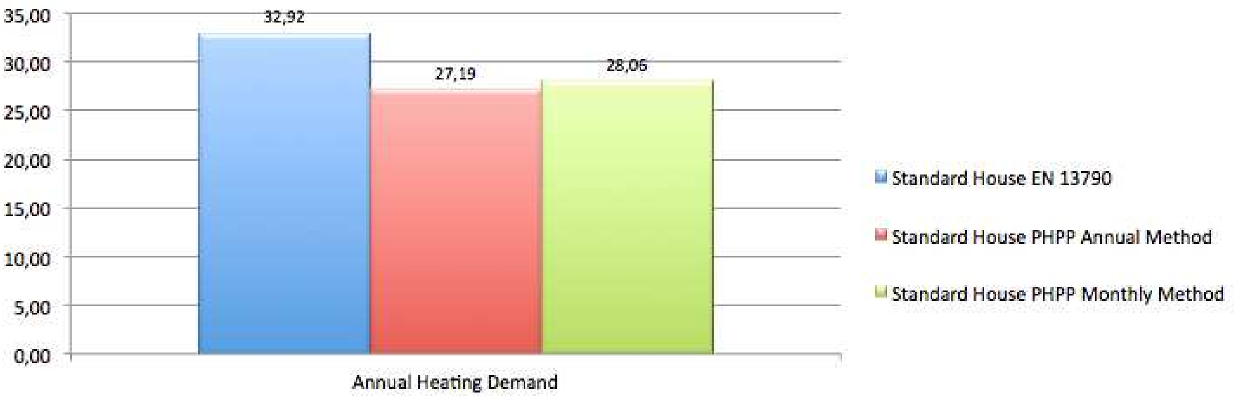


Figure. 10.1. Comparision of obtained results according to EN 13790 and PHPP standard.

As it can be seen, the most comparable results have been obtained for calculation made in accordance with EN 1370 and the PHPP Monthly Method. The difference between these values for Annual Heating Demand amounts in 15%. Whereas, the discrepancy between the calculations made in accordance with EN 13790 and the PHPP Annual Method is slightly bigger and it amounts in 17%. It can be generally noticed that the calculations according to EN 13790 gives the highest demands for space heating.

10.2. Future perspectives

One of the further work that can be done to develop the content of this dissertation is the comparison of the cost between the construction of Standard and Passive House in Poland. The calculations of the profitability of construction Passive house in Poland and the payback time of this investment also can be estimated. The economic aspects of passive house construction in Poland can also refer to the availability of suitable materials on the Polish market, prices and profitability of their application.

On the basis of this dissertation, also the more detailed calculations connected with selecting different combinations of heating, domestic hot water and ventilation systems can be performed.

List of references

[1] Passive Buildings; What is a Passive House; retrieved from www.budynkipasywne.pl (accessed January 2014).

[2] Dr .Feist, W.; Passive Houses in Practice in: The Building Physics Calendar; Ernst & Sohn, Berlin, 2007.

[3] Polish Passive House Institute, Construction of the passive house; November 9, 2007.

[4] Dr Feist W., Passivhouse Institute; What is a Passive House?; retrieved from www.passivehouse.com (accessed January 2014).

[5] Dr Feist W.; Passive House in Central Europe, 2008.

[6] Polish Institute of Passive House and Renewable Energy, A passive house - what is it?

[7] Polish Institute of Passive House and Renewable Energy; Information Bulletin; August 2013.

[8] Kopica J., Turski R.; History of passive building.

[9] Dr Feist W., Passivhouse Institute, 15th Anniversary of the Darmstadt - Kranichstein Passive House; September, 2006.

[10] The National Ecological and Social Movement, Passive house - easier for the wallet and the environment; retrieved from www.budynkipasywne.pl (accessed January 2014).

[11] Lipinscy Houses, A short history of passive building in Europe; retrieved; October, 2011.

[12] Passive Houses – history, retrieved from http://www.domypasywne.net.pl/historia.php, 2010 (accessed January 2014).

[13] Dr Juchniewicz-Lipińska L., dr Lipiński M., Design Office Lipińscy Houses; Certified Passive House.

[14] Passive House Institute; PHPP – the energy balance and Passive House planning tool.

[15] Węglarz A., Stępień R; Institute for Sustainable Development in cooperation with National Energy Conservation Agency; Passive House; Warsaw: Foundation Institute for Sustainable Development, ISBN 978-83-89495-02-0; November, 2011.

[16] Passive House Institute, About Passive House - What is a Passive House?, 2012.

[17] The National Ecological and Social Movement; Passive buildings - masters of energy-saving; 2006.

[18] MuratorDom; The benefits of passive house construction ; retrieved from http://muratordom.pl/eko-murator/buduj-ekologicznie/korzysci-z-budowy-domu-pasywnego, 116_6977.html (accessed January 2014).

[19] Certification of passive houses; retrieved fromhttp://www.intelcad.pl/nowa/index.php?option=com_content&view=article&id=12&Itemid=77 (accessed January 2014).

[20] Dipl. Schlagowski G.; Future constructions, the interview.

[21] Polish Institute of Passive House and Renewable Energy, Certification, retrieved from http://www.pibp.pl/?page_id=97 (accessed January 2014).

[22] International Passive House Association, Passive House certification criteria, retrieved from http://www.passivehouse-international.org/index.php?page_id=150 (accessed January 2014).

[23] Dr Geryło R., Conditions of energy - efficient constructions.

[24] Standard PN-EN 12831:2006. Heating systems in buildings - Calculation design method for the thermal load.

[25] Ministry of Foreign Affairs, Climatic conditions, retrieved from http://www.poland.gov.pl/warunki,klimatyczne,6209.html (accessed January 2014).

[26] Firląg S.- Passive House Institute at NAPE, dr Schnieders J. – Passivhaus Institut; Passive building in central Poland.

[27] Górnicz J., Solar energy; January 11, 2009.

[28] Institute of Meteorology and Water Management, retrieved from http://www.imgw.pl/klimat/# (accessed January 2014).

[29] Żuchowski T., New energy standards for buildings - design and build energy efficiently; September 12, 2013.

[30] The National Fund for Environmental Protection and Water Management, Information about the program.

[31] Idczak M., Firląg S. - Passive House Institute; Windows in passive houses.

[32] Firląg S., Passive House Institute at NAPE; Introduction to the passive constructions.

[33] Eco Custom Homes, Passive House Windows, retrieved from http://newsroom.ecocustomhomes.com/?p=69162 (accessed January 2014).

[34] Passive House Windows: U-values (U-factors)/R-values; November, 2012.

[35] Dipl. Schlagowski G. - Polish Passive House Institute; Energy efficient - passive Building.

[36] Passive House Institute, Insulation; september, 2006.

[37] The National Ecological and Social Movement; External partitions - walls, roof, foundations.

[38] The National Ecological and Social Movement, Tightness of the external partitions.

[39] Passive House Institute, Air Tightness to Avoid Structural Damages; retrieved from; September, 2006.

[40] Airtightness requirement, retrieved from http://www.bionic3.de (accessed January 2014).

[41] Passive House Institute, Design avoiding thermal bridges - preferable not only for Passive Houses.

[42] The National Ecological and Social Movement, Shaping the architecture of passive houses.

[43] Passive House Institute, This will only work in a Passive House: Heating with nothing other than fresh air; September, 2006.

[44] The National Ecological and Social Movement, Ventilation and Heating.

[45] Passive House Alliance, What Is Passive House?; 2014.

[46] Passive House Institute, Why a mechanical ventilation system is recommended - at least in Passive Houses; September, 2006.

[47] Feist W., Munzenberg U., Thumulla J.; Basics of Passive Construction; Polish Passive House Institute; ISBN 9788392380702; 2009.

[48] PN- EN ISO 10211:1998;Thermal bridges in building construction-Heat flows and surface temperatures–Part 1:General calculation methods.

[49] Okolowska A., Laskowski P.; Passive House in Poland ; MuratorDom; 2007.

[50] Cross Ventilation; retrieved from http://www.sustainablebuildings.org/wiki/index.php/Cross_Ventilation; (accessed May 2014).

[51] PHPP (Passive House Planning Package); Version 7 (2012); Passive House Institute.

[52] Certified Passive House Glazing and Transaprent Components; Version 2.0; Passive House Institute; June 2012.

[53] Zehnder ComfoAir 200 – Specifications; Zehnder.

[54] Heating period started. How to cope with dry air?, November 2012.

[55] The whole truth about the enthalpy recuperator, retrieved from http://www.rekuperatory.pl/dowiedz-sie-wiecej/cala-prawda-o-rekuperatorze-entalpicznym (accessed May 2014).

[56] Bypass in the recuperator; retrieved from http://rekuperacjalodz.pl/tmasl-32/48-bypass-w-rekuperatorze.html (accessed May 2014).

[57] Viessmann; retrieved from http://www.viessmann.pl/pl/dom-jednorodzinny/Ogrzewanie/Wentylacja-mechaniczna-rekuperacja/Rekuperator-Vitovent-300-odzysk-ciepla.html.

[58] Stratified Solar Storage Tank Strato-therm+; Lochinvar‘s catalog.

[59] Żuchowski S.; Stratified buffer tanks; January 2012.

[60] Thermal stratification (solar heating); retrieved from http://www.solarserver.com/knowledge/lexicon/t/thermal-stratification-solar-heating.html (accessed May 2014).

[61] Solar Hot Water Basics; retrieved from http://www.apricus.com/html/solar_hot_water_basics.htm#.U7WB3qjlEXy (accessed May 2014).

[62] Stratified storage principle of operation; retrieved from http://www.arpena.pl/index.php/wiedza/zasady-dzialania-urzadzen/zasobnik-warstwowy (accessed May 2014).

[63] Vacuum tube solar collectors Apricus company; April 2014.

[64] Marciniak P.; Passive House for Polish Climate, Master thesis, 2013.

[65] PN EN ISO 6946 “"Building components and building elements. Thermal resistance and the heat transfer coefficient. The method of calculation."

[66] THERM 7.2 software.

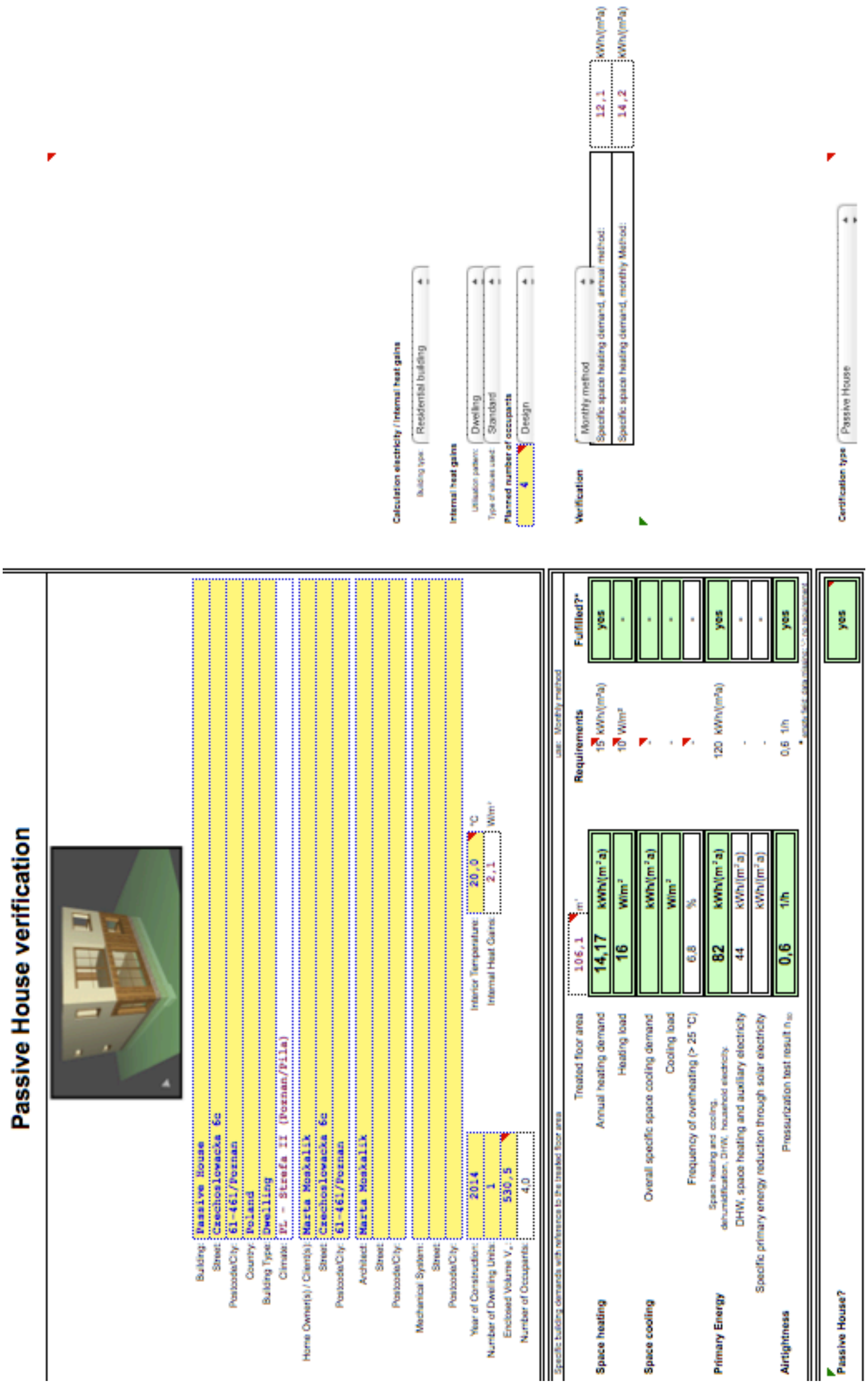
[67] Window frame, Certified Passive House Component; Passive House Institute.

[68] Window glazing, Certified Passive House Component; Passive House Institute.

[69] EN ISO 13790 “Energy performance of buildings – Calculation of energy use for space heating and cooling”.

Annex 1.1: Passive House

Annex 1.1.1: “Verification“ Worksheet



Passive House verification

Building:	Passive House
Street:	Czechoslowacka 6c
Postcode/City:	61-461/Poznan
Country:	Poland
Building Type:	Dwelling
Climate:	PL - Strefa II (Poznan/Pila)
Home Owner(s) / Client(s):	Marta Moskalik
Street:	Czechoslowacka 6c
Postcode/City:	61-461/Poznan
Architect:	Marta Moskalik
Street:	
Postcode/City:	
Mechanical System:	
Street:	
Postcode/City:	
Year of Construction:	2014
Number of Dwelling Units:	1
Enclosed Volume V_e:	530,5
Number of Occupants:	4,0
Interior Temperature:	20,0 °C
Internal Heat Gains:	2,1 W/m²

Specific building demands with reference to the treated floor area — use: Monthly method

				Requirements	Fulfilled?*
	Treated floor area	106,1	m²		
Space heating	Annual heating demand	14,17	kWh/(m²a)	15 kWh/(m²a)	yes
	Heating load	16	W/m²	10 W/m²	-
Space cooling	Overall specific space cooling demand		kWh/(m²a)		-
	Cooling load		W/m²	-	-
	Frequency of overheating (> 25 °C)	6,8	%		-
Primary Energy	Space heating and cooling, dehumidification, DHW, household electricity	82	kWh/(m²a)	120 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	44	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	-
Airtightness	Pressurization test result n_{50}	0,6	1/h	0,6 1/h	yes

* empty field: data missing; '-': no requirement

Passive House?	yes

Calculation electricity / internal heat gains
Building type: Residential building

Internal heat gains
Utilisation pattern: Dwelling
Type of values used: Standard
Planned number of occupants: 4 — Design

Verification: Monthly method

Specific space heating demand, annual method:	12,1	kWh/(m²a)
Specific space heating demand, monthly Method:	14,2	kWh/(m²a)

Certification type: Passive House

Annex 1.1.2: "Areas" Worksheet

Passive House verification

AREAS DETERMINATION

Building: Passive House   Heating demand 14 kWh/(m²a)

Group Nr.	Area group	Temp. zone	Area	Unit	Comments (Summary)	Building element overview	Average U-Value [W/(m²K)]
1	Treated Floor Area		106,06	m²	Living area or useful area within the thermal envelope		
2	North Windows	A	3,13	m²	Results are from the Windows worksheet.	North Windows	0,649
3	East Windows	A	3,50	m²		East Windows	0,631
4	South Windows	A	21,31	m²		South Windows	0,558
5	West Windows	A	3,13	m²		West Windows	0,649
6	Horizontal Windows	A	0,00	m²		Horizontal Windows	
7	Exterior Door	A	5,58	m²	Please subtract area of door from respective building element	Exterior Door	0,770
8	Exterior Wall - Ambient	A	129,07	m²	Window areas are subtracted from the individual areas specified in the "Windows" worksheet.	Exterior Wall - Ambient	0,092
9	Exterior Wall - Ground	B	0,00	m²	Temperature Zone "A" is ambient air.	Exterior Wall - Ground	
10	Roof/Ceiling - Ambient	A	57,80	m²	Temperature zone "B" is the ground.	Roof/Ceiling - Ambient	0,089
11	Floor slab / basement ceiling	B	51,55	m²		Floor slab / basement ceiling	0,099
12			0,00	m²	Temperature zones "A", "B","P" and "X" may be used. NOT "I"		
13			0,00	m²	Temperature zones "A", "B","P" and "X" may be used. NOT "I" Factor for X		
14		X	0,00	m²	Temperature zone "X": Please provide user-defined reduction factor (0 < f, < 1): 75%		
						Thermal Bridge Overview	Ψ [W/(mK)]
15	Thermal Bridges Ambient	A	3,60	m	Units in m	Thermal Bridges Ambient	0,001
16	Perimeter Thermal Bridges	P	0,00	m	Units in m; temperature zone "P" is perimeter (see Ground worksheet).	Perimeter Thermal Bridges	
17	Thermal Bridges Floor Slab	B	0,00	m	Units in m	Thermal Bridges Floor Slab	
18	Partition Wall to Neighbour	I	0,00	m²	No heat losses, only considered for the heating load calculation.	Partition Wall to Neighbour	
Total thermal envelope			275,07	m²		Average Therm. Envelope	0,162

Area input

Area Nr.	Building element description	Group Nr.	Assigned to group	Quantity	x (	a [m]	x	b [m]	+	User-Determined [m²]	-	User Subtraction [m²]	-	Subtraction window areas [m²]	) =	Area [m²]	Selection of the corresponding building element assembly	Nr.	U-Value [W/(m²K)]
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	106,06	-				) =	106,1			
	North Windows	2	North Windows	Please complete in Windows worksheet only!												3,1	From Windows sheet		0,649
	East Windows	3	East Windows													3,5	From Windows sheet		0,631
	South Windows	4	South Windows													21,3	From Windows sheet		0,558
	West Windows	5	West Windows													3,1	From Windows sheet		0,649
	Horizontal Windows	6	Horizontal Windows													0,0	From Windows sheet		0,000
	Exterior Door	7	Exterior Door	1	x (		x		+	5,58	-		) -		=	5,6	U-Value Exterior Door		0,77
1	Exterior wall south (plaster	8	Exterior Wall - Ambient	1	x (		x		+	18,07	-	1,12	) -	10,7	=	6,3	Exterior wall (plaste	1	0,092
2	Exterior wall north (plaster	8	Exterior Wall - Ambient	1	x (		x		+	24,75	-	1,43	) -	0,0	=	23,3	Exterior wall (plaste	1	0,092
3	Exterior wall west (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	42,14	-	1,34	) -	3,1	=	37,7	Exterior wall (plaste	1	0,092
4	Exterior wall east (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	33,90	-	5,22	) -	0,6	=	28,1	Exterior wall (plaste	1	0,092
5	Exterior wall south (panels)	8	Exterior Wall - Ambient	1	x (		x		+	19,02	-	1,12	) -	10,7	=	7,2	Exterior wall (panels	2	0,091
6	Exterior wall north (panels)	8	Exterior Wall - Ambient	1	x (		x		+	12,33	-	0,94	) -	3,1	=	8,3	Exterior wall (panels	2	0,091
7	Exterior wall west (panels)	8	Exterior Wall - Ambient	1	x (		x		+	3,28	-	3,20	) -	0,0	=	0,1	Exterior wall (panels	2	0,091
8	Exterior wall east (panels)	8	Exterior Wall - Ambient	1	x (		x		+	11,52	-	1,69	) -	2,9	=	6,9	Exterior wall (panels	2	0,091
9					x (		x		+		-		) -	0,0	=			4	
10	Floor slab	11	Floor slab / basement ceiling	1	x (		x		+	51,55	-		) -	0,0	=	51,6	Ground floor	3	0,099
11	Lintels - windows (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	1,60	-		) -	0,0	=	1,6	Lintels (plaster)	6	0,100
12	Lintels - windows (panels)	8	Exterior Wall - Ambient	1	x (		x		+	3,15	-		) -	0,0	=	3,2	Lintels (panels)	7	0,099
13	Lintels - door (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	0,29	-		) -	0,0	=	0,3	Lintels (plaster)	6	0,100
14	Lintels - door (panels)	8	Exterior Wall - Ambient	1	x (		x		+	0,29	-		) -	0,0	=	0,3	Lintels (panels)	7	0,099
15	Roof - joist beam 1	10	Roof/Ceiling - Ambient	1	x (		x		+	1,36	-		) -	0,0	=	1,4	Roof - joist 1	5	0,133
16	Roof - joist beam 2	10	Roof/Ceiling - Ambient	1	x (		x		+	1,36	-		) -	0,0	=	1,4	Roof - joist 2 (murla	10	0,131
17	Roof - joist beam 3	10	Roof/Ceiling - Ambient	1	x (		x		+	1,36	-		) -	0,0	=	1,4	Roof - joist 3	11	0,129
18	Roof - insulation	10	Roof/Ceiling - Ambient	1	x (		x		+	52,49	-		) -	0,0	=	52,5	Roof - insulation - m	15	0,085
19	Roof - gutter	10	Roof/Ceiling - Ambient	1	x (		x		+	1,23	-		) -	0,0	=	1,2	Roof - gutter (rynna	14	0,095
20	Wall - spine beam (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	0,66	-		) -	0,0	=	0,7	Wall - Spine beam (	8	0,100
21	Wall - spine beam (panels)	8	Exterior Wall - Ambient	1	x (		x		+	1,19	-		) -	0,0	=	1,2	Wall - Spine beam (	9	0,099
22	Pillar (panels)	8	Exterior Wall - Ambient	1	x (		x		+	1,16	-		) -	0,0	=	1,2	Wall - Pillar (panels)	16	0,099
23	Pillar (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	2,85	-		) -	0,0	=	2,9	Wall - Pillar (plaster)	17	0,100
24					x (		x		+		-		) -	0,0	=			0	

Thermal Bridge Inputs

No.	Thermal bridge description	Group Nr.	Assigned to group	Quantity	x (	User determined length [m]	-	Subtraction user-determined length [m]	)=	Length ℓ [m]	Input of thermal bridge heat loss coefficient W/(mK)	Ψ W/(mK)
1	Windows + door(jamb)	8	Exterior Wall - Ambient	1	x (	89,30	-		) =	89,30	Windows + door(jamb)	0,021
2	Stairs	15	Thermal Bridges Ambient	1	x (	3,60	-		) =	3,60	Stairs	0,001
3	Roof - exterior wall	10	Roof/Ceiling - Ambient	1	x (	30,91	-		) =	30,91	Roof - exterior wall	-0,021
4	Floor slab - exterior wall	11	Floor slab / basement ceiling	1	x (	30,91	-		) =	30,91	Floor slab - exterior wall	-0,092
5	Exterior wall corner	8	Exterior Wall - Ambient	4	x (	5,34	-		) =	21,36	Exterior wall corner	-0,054
6	Spine beam	8	Exterior Wall - Ambient	1	x (	30,91	-		) =	30,91	Spine beam	0,023
7					x (		-		) =			

Annex 1.1.3: “U-List“ Worksheet

Passive House verification

U - LIST

Compilation of the building elements calculated in the U-Values worksheet and other construction types from databases.

	Type		
Assembly No.	Assembly description	Total thickness	U-Value
		m	W/(m²K)
1	Exterior wall (plaster)	0,567	0,092
2	Exterior wall (panels)	0,580	0,091
3	Ground floor	0,520	0,099
4			
5	Roof - joist 1	0,795	0,133
6	Lintels (plaster)	0,567	0,100
7	Lintels (panels)	0,580	0,099
8	Wall - Spine beam (plaster) - wieniec	0,567	0,100
9	Wall - Spine beam (panels) - wieniec	0,580	0,099
10	Roof - joist 2 (murłata)	0,895	0,131
11	Roof - joist 3	0,995	0,129
12			
13			
14	Roof - gutter	0,567	0,095
15	Roof - insulation - medium height	0,885	0,085
16	Wall - Pillar (panels)	0,580	0,099
17	Wall - Pillar (plaster)	0,567	0,100
18			
19			

Annex 1.1.4: "U-Values"

Passive House verification

U-VALUES OF BUILDING ELEMENTS

Building: Passive House

Wedge shaped building element layers and still air spaces -> Secondary calculation to the right

Assembly No. 1 — Building assembly description: Exterior wall (plaster) — Interior insulation?

Heat transfer resistance [m²K/W] — interior Rsi: 0,13 — exterior Rse: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Airbrick - Porotherm Dry	0,238					250
3.	Styrofoam - Termo Organi	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							

Percentage of Sec. 2 — Percentage of Sec. 3 — Total: 56,7 cm

U-Value: 0,092 W/(m²K)

Assembly No. 2 — Building assembly description: Exterior wall (panels) — Interior insulation?

Heat transfer resistance [m²K/W] — interior Rsi: 0,13 — exterior Rse: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Airbrick - Porotherm Dry	0,238					250
3.	Styrofoam - Termo Organi	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2 — Percentage of Sec. 3 — Total: 58,0 cm

U-Value: 0,091 W/(m²K)

Assembly No. 3 — Building assembly description: Ground floor — Interior insulation?

Heat transfer resistance [m²K/W] — interior Rsi: 0,17 — exterior Rse: 0,00

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Ceramic tiles	1,070					10
2.	Concrete screed	1,300					50
3.	Styrofoam - Termo Organi	0,031					300
4.	Damp insulation	0,180					10
5.	Concrete screed	1,300					50
6.	Compacted rubble	0,770					100
7.							
8.							

Percentage of Sec. 2 — Percentage of Sec. 3 — Total: 52,0 cm

U-Value: 0,099 W/(m²K)

Assembly No. Building assembly description: **4** Roof - joist 1 | Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,10 exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Precast beam and block	0,649					240
6.	Mineral wool - Isover	0,030					150
7.	Plasterboard	0,230					25
8.							

Percentage of Sec. 2: 10,0% Percentage of Sec. 3: Total: 79,5 cm

U-Value: 0,133 W/(m²K)

Assembly No. Building assembly description: **5** Lintels (plaster) | Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,13 exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Concrete	1,300	Reinforced concrete	1,700			250
3.	Styrofoam - Termo Organ	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 55,0% Percentage of Sec. 3: Total: 56,7 cm

U-Value: 0,100 W/(m²K)

Assembly No. Building assembly description: **6** Lintels (panels) | Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,13 exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Concrete	1,300	Reinforced concrete	1,700			250
3.	Styrofoam - Termo Organ	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 55,0% Percentage of Sec. 3: Total: 58,0 cm

U-Value: 0,099 W/(m²K)

Assembly No.	Building assembly description					Interior insulation?
7	Wall - Spine beam (plaster) - wieniec					

Heat transfer resistance [m²K/W] interior Rsi : 0,13
exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organi	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
							56,7 cm

U-Value: 0,100 W/(m²K)

Assembly No.	Building assembly description					Interior insulation?
8	Wall - Spine beam (panels) - wieniec					

Heat transfer resistance [m²K/W] interior Rsi : 0,13
exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organi	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
							58,0 cm

U-Value: 0,099 W/(m²K)

Assembly No.	Building assembly description					Interior insulation?
9	Roof - joist 2 (murłata)					

Heat transfer resistance [m²K/W] interior Rsi : 0,10
exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Brick wall	0,770					100
6.	Precast beam and block s	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
				Percentage of Sec. 2		Percentage of Sec. 3	Total
				9,0%			89,5 cm

U-Value: 0,131 W/(m²K)

Assembly No.	Building assembly description	Interior insulation?
10	Roof - joist 3	

Heat transfer resistance [m²K/W] interior R_{si}: 0,10 exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Brick wall	0,770					200
6.	Precast beam and block	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
			Percentage of Sec. 2	9,0%	Percentage of Sec. 3		Total 99,5 cm

U-Value: 0,129 W/(m²K)

Assembly No.	Building assembly description	Interior insulation?
11	Roof - gutter	

Heat transfer resistance [m²K/W] interior R_{si}: 0,10 exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roof membrane	0,040					2
2.	Styrofoam - Termo Organ	0,031					150
3.	Precast beam and block	0,649					240
4.	Mineral wool - Isover	0,030					150
5.	Plasterboard	0,230					25
6.							
7.							
8.							
			Percentage of Sec. 2		Percentage of Sec. 3		Total 56,7 cm

U-Value: 0,095 W/(m²K)

Assembly No.	Building assembly description	Interior insulation?
12	Roof - insulation - medium height	

Heat transfer resistance [m²K/W] interior R_{si}: 0,10 exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Hollow core	0,270					100
5.	Styrofoam - Termo Organ	0,031					150
6.	Precast beam and block	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
			Percentage of Sec. 2	9,0%	Percentage of Sec. 3		Total 88,5 cm

U-Value: 0,085 W/(m²K)

Assembly No.	Building assembly description	Interior insulation?
13	Wall - Pillar (panels)	

Heat transfer resistance [m²K/W] interior R_{si}: 0,13
exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ:	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2 | Percentage of Sec. 3 | Total 58,0 cm

U-Value: 0,099 W/(m²K)

Assembly No.	Building assembly description	Interior insulation?
14	Wall - Pillar (plaster)	

Heat transfer resistance [m²K/W] interior R_{si}: 0,13
exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ:	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							

Percentage of Sec. 2 | Percentage of Sec. 3 | Total 56,7 cm

U-Value: 0,100 W/(m²K)

Annex 1.1.5: “Ground“ Worksheet

Passive House verification

HEAT LOSSES VIA THE GROUND

Ground Characteristics			
Thermal Conductivity	λ	2,0	W/(mK)
Heat Capacity	ρc	2,0	MJ/(m³K)
Periodic Penetration Depth	δ	3,17	m

Climate Data			
Av. Indoor Temp. Winter	T_i	20,0	°C
Av. Indoor Temp. Summer	T_i	25,0	°C
Average Ground Surface Temperature	$T_{g,ave}$	9,3	°C
Amplitude of $T_{g,ave}$	$T_{g,\hat{}}$	10,0	°C
Length of the Heating Period	n	7,2	months
Heating Degree Hours - Exterior	G_t	89,3	kKh/a

Building Data							
Floor Slab Area	A	69,0	m²	U-value floor slab/basement ceiling	U_f	0,099	W/(m²K)
Floor Slab Perimeter	P	34,4	m	Thermal bridges floor slab/basement cei	Ψ_B*l	0,00	W/K
Charact. Dimension of Floor Slab	B'	4,01	m	U-value floor slab/basement ceiling incl.	U_f'	0,099	W/(m²K)
				Eq. Thickness Floor	d_t	20,20	m

Floor Slab Type (select only one)			
	Heated Basement or Underground Floor Slab		Unheated basement
x	Slab on Grade		Suspended Floor

For Basement or Underground Floor Slab							
Basement Depth	z		m	U-Value Belowground Wall	U_{wB}		W/(m²K)
Additionally for Unheated Basements				Height Aboveground Wall	h		m
Air Change Unheated Basement	n		h⁻¹	U-Value Aboveground Wall	U_W	0,092	W/(m²K)
Basement Volume	V		m³	U-Value Basement Floor Slab	U_{fB}		W/(m²K)

For Perimeter Insulation for Slab on Grade				For Suspended Floor			
Perimeter Insulation Width/Depth	D	1,00	m	U-Value Crawl Space	U_{Crawl}		W/(m²K)
Perimeter Insulation Thickness	d_n	0,12	m	Height of Crawl Space Wall	h		m
Conductivity Perimeter Insulation	λ_n	0,031	W/(mK)	U-Value Crawl Space Wall	U_W		W/(m²K)
				Area of Ventilation Openings	εP		m²
Orientation of the Perimeter Ins.	horizontal			Wind Velocity at 10 m Height	v	4,0	m/s
(check only one field)	vertical	x		Wind Shield factor	f_W	0,05	-

Additional Thermal Bridge Heat Losses at Perimeter							
Phase Shift	β		months	Steady-State Fraction	$\Psi_{P,stat}$*l	0,000	W/K
				Harmonic Fraction	$\Psi_{P,harm}$*l	0,000	W/K

Groundwater Correction							
Depth of the Groundwater Table	z_w	3,0	m	Transm. Belowground El. (w/o Ground)	L_{eg}	6,83	W/K
Groundwater Flow Rate	q_w	0,05	m/d	Relative Insulation Standard	d_t/B'	5,04	-
				Relative Groundwater Depth	z_w/B'	0,75	-
Groundwater Correction Factor	G_w	1,000868	-	Relative Groundwater Velocity	l/B'	0,21	-

Basement or Underground Floor Slab							
Eq. Thickness Floor Slab	d_t		m	Phase Shift	β		months
U-Value Floor Slab	U_{bf}		W/(m²K)	Exterior Periodic Transmittance	L_{pe}		W/K
Eq. Thickness Basement Wall	d_w		m				
U-Value Wall	U_{bw}		W/(m²K)				
Steady-State Transmittance	L_s		W/K				

Unheated Basement							
Steady-State Transmittance	L_S		W/K	Phase Shift	β		months
				Exterior Periodic Transmittance	L_{pe}		W/K

Slab on Grade							
Heat Transfer Coefficient	U_0	0,09	W/(m²K)	Phase Shift	β	1,44	months
Eq. Ins. Thickness Perimeter Ins.	d'	7,62	m	Exterior Periodic Transmittance	L_{pe}	3,26	W/K
Perimeter Insulation Correction	ΔΨ	-0,02	W/(mK)				
Steady-State Transmittance	L_S	5,72	W/K				

Suspended Floor Above a Ventilated Crawl Space (at max. 0.5 m Below Ground)							
Eq. Ins. Thickness Crawl Space	d_g		m	Phase Shift	β		months
U-Value Crawl Space Floor Slab	U_g		W/(m²K)	Exterior Periodic Transmittance	L_{pe}		W/K
U-Value Crawl Space Wall & Vent.	U_X		W/(m²K)				
Steady-State Transmittance	L_S		W/K				

Interim Results							
Phase Shift	β	1,44	months	Steady-State Heat Flow	Φ_{stat}	61,4	W
Steady-State Transmittance	L_S	5,72	W/K	Periodic Heat Flow	Φ_{harm}	12,0	W
Exterior Periodic Transmittance	L_{pe}	3,26	W/K	Heat Losses During Heating Period	Q_{tot}	386	kWh

Ground reduction factor for "Annual Heating Demand" sheet **0,63**

Monthly Average Ground Temperatures for Monthly Method

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average Value
Winter	7,5	6,4	6,4	7,7	9,9	12,4	14,5	15,7	15,6	14,3	12,1	9,6	11,0
Summer	8,3	7,2	7,3	8,6	10,7	13,2	15,3	16,5	16,4	15,1	12,9	10,4	11,8

Design Ground Temperature for Heating Load Sheet 6,4 **for Cooling Load Sheet** 16,5

Annex 1.1.6: “Windows“ Worksheet

Passive House verification

REDUCTION FACTOR SOLAR RADIATION, WINDOW U-VALUE

Building: Passive House

Annual heating demand: 14 kWh/(m²a)

Heating degree hours: 89,3

Climate: PL - Strefa II (Poznan/Pila)

Window area orientation	Global radiation (cardinal points)	Shading	Dirt	Non-perpendicular incident radiation	Glazing fraction	g-Value	Reduction factor for solar radiation	Window area	Window U-Value	Glazing area	Average global radiation	Transmission losses	Heat gains solar radiation
maximum:	kWh/(m²a)	0,75	0,95	0,85				m²	W/(m²K)	m²	kWh/(m²a)	kWh/a	kWh/a
North	100	0,78	0,95	0,85	0,774	0,50	0,49	3,13	0,65	2,4	100	181	76
East	229	0,77	0,95	0,85	0,796	0,50	0,49	3,50	0,63	2,8	229	197	198
South	427	0,79	0,95	0,85	0,903	0,50	0,58	21,31	0,56	19,3	427	1063	2638
West	229	0,77	0,95	0,85	0,774	0,50	0,48	3,13	0,65	2,4	229	181	172
Horizontal	345	1,00	0,95	0,85	0,000	0,00	0,00	0,00	0,00	0,0	345	0	0
	Total or Average Value for All Windows.					0,50	0,55	31,07	0,58	26,9		1623	3084

					Window rough openings		Installed		Glazing		Frame		g-Value	U-Value		Ψ-Spacer
Quan-tity	Description	Deviation from north	Angle of inclination from the horizontal	Orientation	Width	Height	in Area in the Areas worksheet	Nr.	Select glazing from the WinType worksheet	Nr.	Select window from the WinType worksheet	Nr.	Perpen-dicular Radiation	Glazing	Frames (centre)	Ψ_{spacer} (centre)
		Degrees	Degrees		m	m	Select:		Select:		Select:		-	W/(m²K)	W/(m²K)	W/(mK)
1	South	180	90	South	2,000	1,450	Exterior	1	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	South	180	90	South	3,300	2,350	Exterior	1	Custom	1	Custom	1	0,50	0,49	0,66	0,021
2	North	0	90	North	1,400	0,600	Exterior	6	Custom	1	Custom	1	0,50	0,49	0,67	0,021
1	North	0	90	North	1,000	1,450	Exterior	6	Custom	1	Custom	1	0,50	0,49	0,66	0,021
2	East	90	90	East	1,000	1,450	Exterior	8	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	East	90	90	East	1,000	0,600	Exterior	4	Custom	1	Custom	1	0,50	0,49	0,67	0,021
2	West	270	90	West	1,400	0,600	Exterior	3	Custom	1	Custom	1	0,50	0,49	0,67	0,021
1	West	270	90	West	1,000	1,450	Exterior	3	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	South	180	90	South	2,000	1,450	Exterior	5	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	South	180	90	South	3,300	2,350	Exterior	5	Custom	1	Custom	1	0,50	0,49	0,66	0,021
								0		0		0				

Installation									Results (unhide cells to make U- & Ψ-values from WinType worksheet visible)				Frame-U-values from WinTpye worksheet			
Left 1/0	Right 1/0	Bottom 1/0	Top 1/0	$\Psi_{installation}$ left	$\Psi_{installation}$ right	$\Psi_{installation}$ bottom	$\Psi_{installation}$ top	$\Psi_{installation}$ Average value	Window Area	Glazing Area	U-Value Window	Glazed Fraction per Window	Frame left	Frame right	Frame bottom	Frame top
				W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	m²	m²	W/(m²K)	%	W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)
1	1	1	1					0,010	2,9	2,51	0,58	87%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	7,8	7,11	0,55	92%	0,64	0,64	0,72	0,64
1	1	1	1					0,011	1,7	1,24	0,68	74%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	1,5	1,18	0,62	81%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	2,9	2,36	0,62	81%	0,64	0,64	0,72	0,64
1	1	1	1					0,011	0,6	0,43	0,69	71%	0,64	0,64	0,72	0,64
1	1	1	1					0,011	1,7	1,24	0,68	74%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	1,5	1,18	0,62	81%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	2,9	2,51	0,58	87%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	7,8	7,11	0,55	92%	0,64	0,64	0,72	0,64

Frame measures from WinType worksheet

p	Width - Left	Width - Right	Width - Below	Width - Above	Area left	Area right	Area bottom	Area top	Total area	Glazing edge length left	Glazing edge length right	Glazing edge length bottom	Glazing edge length top	Total glazing edge length	Installation length left	Installation length right	Installation length bottom	Installation length top	Total installation length
	m	m	m	m	m²	m²	m²	m²	m²	m	m	m	m	m	m	m	m	m	m
	0,06	0,06	0,06	0,06	0,08	0,08	0,12	0,12	0,39	1,33	1,33	1,88	1,88	6,44	1,45	1,45	2,00	2,00	6,90
	0,06	0,06	0,06	0,06	0,13	0,13	0,19	0,19	0,64	2,23	2,23	3,18	3,18	10,84	2,35	2,35	3,30	3,30	11,30
	0,06	0,06	0,06	0,06	0,03	0,03	0,08	0,08	0,22	0,48	0,48	1,28	1,28	3,54	0,60	0,60	1,40	1,40	4,00
	0,06	0,06	0,06	0,06	0,08	0,08	0,06	0,06	0,27	1,33	1,33	0,88	0,88	4,44	1,45	1,45	1,00	1,00	4,90
	0,06	0,06	0,06	0,06	0,08	0,08	0,06	0,06	0,27	1,33	1,33	0,88	0,88	4,44	1,45	1,45	1,00	1,00	4,90
	0,06	0,06	0,06	0,06	0,03	0,03	0,06	0,06	0,17	0,48	0,48	0,88	0,88	2,74	0,60	0,60	1,00	1,00	3,20
	0,06	0,06	0,06	0,06	0,03	0,03	0,08	0,08	0,22	0,48	0,48	1,28	1,28	3,54	0,60	0,60	1,40	1,40	4,00
	0,06	0,06	0,06	0,06	0,08	0,08	0,06	0,06	0,27	1,33	1,33	0,88	0,88	4,44	1,45	1,45	1,00	1,00	4,90
	0,06	0,06	0,06	0,06	0,08	0,08	0,12	0,12	0,39	1,33	1,33	1,88	1,88	6,44	1,45	1,45	2,00	2,00	6,90
	0,06	0,06	0,06	0,06	0,13	0,13	0,19	0,19	0,64	2,23	2,23	3,18	3,18	10,84	2,35	2,35	3,30	3,30	11,30

	Thermal bridges									Installation length	
n	$\Psi_{glazing\ edge}$ left	$\Psi_{glazing\ edge}$ right	$\Psi_{glazing\ edge}$ bottom	$\Psi_{glazing\ edge}$ top	$\Psi_{installation}$ left	$\Psi_{installation}$ right	$\Psi_{installation}$ bottom	$\Psi_{installation}$ top	Descrip-tion	Glazing	Frames
	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)		m	m
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	6,4	6,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	10,8	11,3
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	North	7,1	8,0
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	North	4,4	4,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	East	8,9	9,8
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	East	2,7	3,2
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	West	7,1	8,0
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	West	4,4	4,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	6,4	6,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	10,8	11,3

Annex 1.1.7: “WinType“ Worksheet

Passive House verification

GLAZING ACCORDING TO CERTIFICATION

Go to curtain wall facades / window frames from line 99 onwards

	Type		
Assem-bly No.	Glazing	g-Value	U_g-Value
			W/(m²K)
1	Custom glazing	0,50	0,49
2			

CURTAIN WALL FACADE / WINDOW FRAME AS PER CERTIFICATE

Go to glazing from line 2 onwards

	Type	U_f-Value				Frame Dimensions			
Assem-bly No.	Window frame	Frame left	Frame right	Frame bottom	Frame top	Width - Left	Width - Right	Width - Below	Width - Above
	Curtain wall facade	Post left	Post right	Beam bottom	Beam top	Post left	Post right	Beam bottom	Beam top
		W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)	m	m	m	m
1	Custom frame	0,64	0,64	0,72	0,64	0,058	0,058	0,058	0,058
2									

Thermal bridges								
Glazing edge thermal bridge				Installation thermal bridge				Curtain wall facades:
$\Psi_{\text{Glazing edge}}$ left	$\Psi_{\text{Glazing edge}}$ right	$\Psi_{\text{Glazing edge}}$ bottom	$\Psi_{\text{Glazing edge}}$ top	$\Psi_{\text{Installation}}$ left	$\Psi_{\text{Installation}}$ right	$\Psi_{\text{Installation}}$ bottom	$\Psi_{\text{Installation}}$ top	χ_{GC} -value Glass carrier
W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/K
0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	

Annex 1.1.8: “Shading“ Worksheet

Passive House verification

CALCULATING SHADING FACTORS

Climate: PL - Strefa II (Poznan/Pila)

Building: Passive House

Latitude: 52,42 °

Orientation	Glazing area m²	Reduction factor r_S
North	2,42	78%
East	2,79	77%
South	19,25	79%
West	2,42	77%
Horizontal	0,00	100%

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing width	Glazing height	Glazing area	Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional shading reduction factor	Horizontal shading reduction factor	Reveal Shading Reduction Factor	Overhang shading reduction factor	Total shading reduction factor
		Degrees	Degrees		m	m		m	m	m	m	m	m	%	%	%	%	%
					w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}	r_H	r_R	r_O	r_S
1	South	180	90	South	1,88	1,33	2,5	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	99%	100%	79%
1	South	180	90	South	3,18	2,23	7,1	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	99%	100%	80%
2	North	0	90	North	1,28	0,48	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	98%	100%	78%
1	North	0	90	North	0,88	1,33	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	97%	100%	78%
2	East	90	90	East	0,88	1,33	2,4	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	96%	100%	77%
1	East	90	90	East	0,88	0,48	0,4	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	96%	100%	77%
2	West	270	90	West	1,28	0,48	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	97%	100%	78%
1	West	270	90	West	0,88	1,33	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	96%	100%	77%
1	South	180	90	South	1,88	1,33	2,5	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	99%	100%	79%
1	South	180	90	South	3,18	2,23	7,1	0,00	0,00	0,05	[illegible]	0,00	0,00	80%	100%	99%	100%	80%

Annex 1.1.9: “Ventilation“ Worksheet

Passive House verification

VENTILATION DATA

Building: Passive House

Treated floor area A_{TFA}		m²	106	*(Areas worksheet)*
Room height h		m	2,5	*(Annual Heating Demand worksheet)*
Room ventilation volume (A_{TFA}*h) =	V_V	m³	265	*(Annual Heating Demand worksheet)*

Type of ventilation system

x	Balanced PH ventilation	*Please Check*
	Pure extract air	

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for screening class	Several sides exposed	One side exposed
No screening	0,10	0,03
Moderate screening	0,07	0,02
High screening	0,04	0,01
Coefficient f	15	20

			for Annual Demand:	for Heating Load:				
Wind protection coefficient, e			0,07	0,18				
Wind protection coefficient, f			15	15	Net Air Volume for Press. Test V_{n50}		Air permeability q_{50}	
Air Change Rate at Press. Test	n_{50}	1/h	0,60	0,60	531	m³	1,16	m³/(hm²)

			for Annual Demand:	for Heating Load:
Excess extract air		1/h	0,00	0,00
Infiltration air change rate	$n_{V,Res}$	1/h	0,084	0,210

Selection of ventilation data input - Results

The PHPP offers two methods for dimensioning the air quantities and choosing the ventilation unit. Fresh air or extract air quantities for residential buildings and parameters for ventilation systems with a maximum of 1 ventilation unit can be determined using the standard planning option in the 'Ventilation' sheet. The 'Additional Vent' sheet has been created for more complex ventilation systems and allows up to 10 different ventilation units to be taken into account. Furthermore, air quantities can be determined on a room-by-room or zone-by-zone basis. Please select your design method here.

Ventilation unit / Heat recovery efficiency design

x	Sheet Ventilation (Standard design)	*(Sheet Ventilation see below)*
	Sheet Extended ventilation	*(Sheet Additional Vent)*
	(Multiple ventilation units, non-residential buildings)	

Mean Air exchange m³/h	Mean Air Change Rate 1/h	Extract air excess (Extract air system) 1/h	Effective heat recovery efficiency Unit [-]	Specific power input Wh/m³	Heat recovery efficiency SHX
108	0,41	0,00	80,0%	0,42	0,0%

SHX efficiency η^*_{SHX} 0%

STANDARD INPUT FOR BALANCED VENTILATION

Ventilation dimensioning for systems with one ventilation unit

	Unit					
Occupancy	m²/P	27				
Number of occupants	P	4,0				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	120		Bathroom		
Extract air rooms		Kitchen	Bathroom	(shower only)	WC	Other
Quantity		1	1		1	3
Extract air requirement per room	m³/h	50	30	20	30	10
Total Extract Air Requirement	m³/h	140				

Design air flow rate (maximum) m³/h 140

Average air change rate calculation

Type of operation	Daily operation duration h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
Maximum		1,00	140	0,53
Standard	24,0	0,77	108	0,41
Basic		0,54	75	0,28
Minimum		0,40	56	0,21
	Average value	0,77	Average air flow rate (m³/h): **108**	Average air change rate (1/h): **0,41**

Selection of ventilation unit with heat recovery

x	Central unit within the thermal envelope.
	Central unit outside of the thermal envelope.

		Heat recovery efficiency Unit η_{HR}	Specific power input [Wh/m³]	Application range [m³/h]	Frost protection required	Unit noise level < 35dB(A)
Ventilation unit selection	ComfoAir 200 - Zehnder	0,92	0,42	60 - 150	yes	no

		Unit	Value	
Conductance value of outdoor air duct	Ψ	W/(mK)	0,284	See calculation below
Length of outdoor air duct		m	1,9	
Conductance value of exhaust air duct	Ψ	W/(mK)	0,370	See calculation below
Length of exhaust air duct		m	1,9	
Temperature of mechanical services room (Enter only if the central unit is outside of the thermal envelope.)		°C		

Room Temperature (°C)	20
Av. Ambient Temp. Heating P. (°C)	3,5
Av. Ground Temp (°C)	9,3

Effective heat recovery efficiency $\eta_{HR,eff}$ **80,0%** η=92%-12%=80%

Effective heat recovery efficiency subsoil heat exchanger

SHX efficiency	η^*_{SHX}	
Heat recovery efficiency SHX	η_{SHX}	0%

Secondary calculation

Ψ-value supply or ambient air duct

Nominal width:	100	mm
Insul. Thickness:	50	mm
Reflective? Please mark with an "x"!		
x Yes		
No		
Thermal conductivity	0,04	W/(mK)
Nominal air flow rate	108	m³/h
Δθ	16	K
Exterior duct diameter	0,100	m
Exterior diameter	0,200	m
α-Interior	17,81	W/(m²K)
α-Surface	2,74	W/(m²K)
Ψ-value	**0,284**	**W/(mK)**
Surface temperature difference	2,721	K

Secondary calculation

Ψ-value extract or exhaust air duct

Nominal width:	100	mm
Insul. Thickness:	30	mm
Reflective? Please mark with an "x"!		
x Yes		
No		
Thermal conductivity	0,04	W/(mK)
Nominal air flow rate	108	m³/h
Δθ	16	K
Exterior duct diameter	0,100	m
Exterior diameter	0,160	m
α-Interior	17,81	W/(m²K)
α-Surface	3,05	W/(m²K)
Ψ-value	**0,370**	**W/(mK)**
Surface temperature difference	3,983	K

Annex 1.1.10: “Annual Heating Demand“ Worksheet

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND

Climate:	PL - Strefa II (Poznan/Pila)	Interior Temperature:	20,0 °C
Building:	Passive House	Building Type/Use:	Dwelling
		Treated Floor Area A_{TFA}:	106,1 m²

Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Temp. Factor f_t		G_t kKh/a		kWh/a	per m² Treated Floor Area
Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	*	89,3	=	1061	10,00
Exterior Wall - Ground	B		*		*	0,63	*		=		
Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	*	89,3	=	458	4,32
Floor slab / basement ceiling	B	51,6	*	0,099	*	0,63	*	89,3	=	288	2,71
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Windows	A	31,1	*	0,585	*	1,00	*	89,3	=	1623	15,30
Exterior Door	A	5,6	*	0,770	*	1,00	*	89,3	=	384	3,62
Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	*	89,3	=	0	0,00
Perimeter TB (length/m)	P		*		*	0,63	*		=		0,00
Ground TB (length/m)	B		*		*	0,63	*		=		
Total of All Building Envelope Areas		275,1									kWh/(m²a)
Transmission Heat Losses Q_T									Total	3813	35,9

	Effective Air Volume, V_V		A_{TFA} m²	*	Clear Room Height m	=	265,2 m³
Ventilation System: Effective Heat Recovery Efficiency of Heat Recovery	η_{eff}	80%					
Efficiency of Subsoil Heat Exchanger	η_{SHX}	0%					
			106,1	*	2,50	=	265,2
		$n_{V,system}$ 1/h		Φ_{HR}		$n_{V,Res}$ 1/h		1/h
Energetically Effective Air Exchange n_V		0,407	* (1 -	0,80	) +	0,084	=	0,165

	V_V m³		n_V 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	265	*	0,165	*	0,33	*	89,3	=	1292	12,2

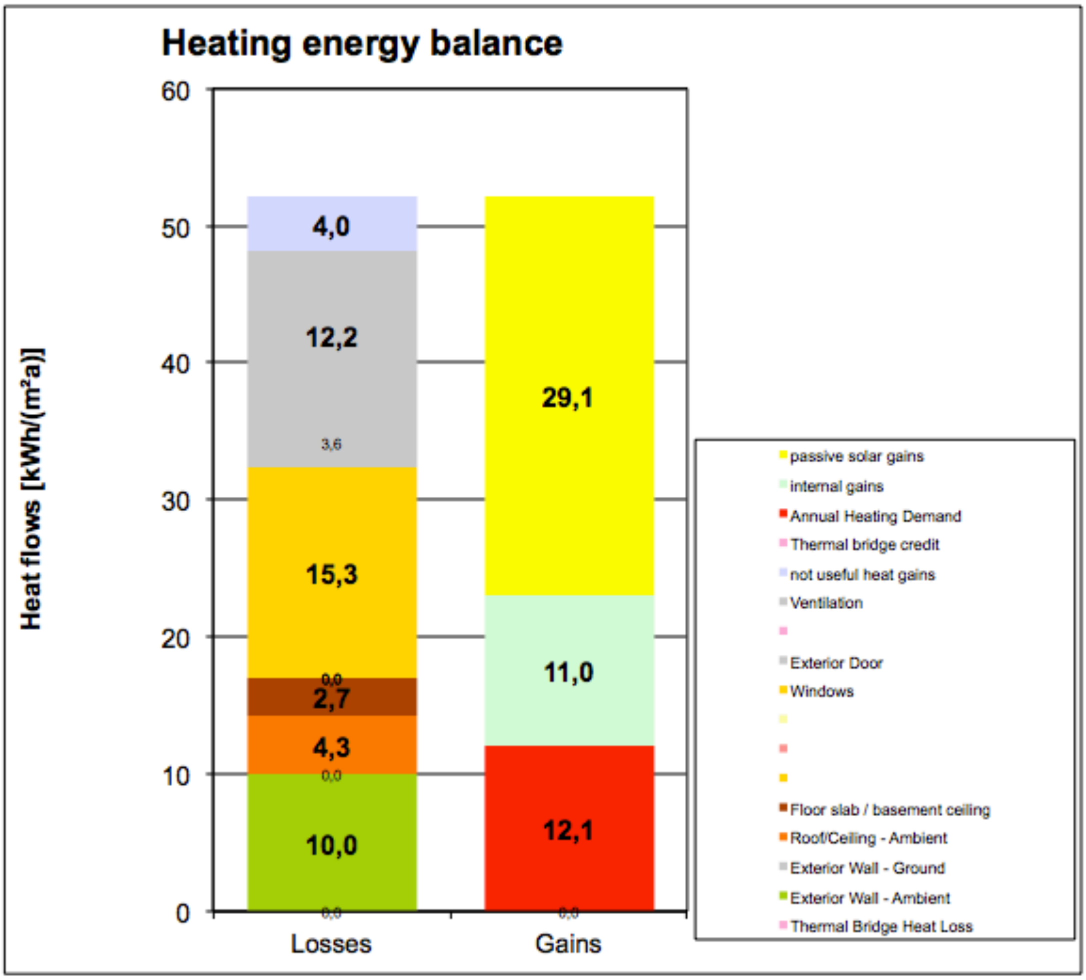
		Q_T kWh/a		Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	3813	+	1292	)	1,0	=	5105	48,1

Orientation of the Area	Reduction Factor See Windows Sheet		g-Value (perp. radiation)		Area m²		Radiation HP kWh/(m²a)		kWh/a	
1. North	0,49	*	0,50	*	3,13	*	100	=	76	
2. East	0,49	*	0,50	*	3,50	*	229	=	198	
3. South	0,58	*	0,50	*	21,31	*	427	=	2638	
4. West	0,48	*	0,50	*	3,13	*	229	=	172	
5. Horizontal	0,00	*	0,00	*	0,00	*	345	=	0	kWh/(m²a)
Available Solar Heat Gains Q_S								Total	3084	29,1

	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	219	*	2,10	*	106,1	=	1170	11,0

			kWh/a	kWh/(m²a)
Free Heat Q_F	Q_S + Q_I	=	4255	40,1
Ratio of Free Heat to Losses	Q_F / Q_L	=	0,83	
Utilisation Factor Heat Gains η_G	$(1 - (Q_F / Q_L)^5) / (1 - (Q_F / Q_L)^6)$	=	90%	
Heat Gains Q_G	η_G * Q_F	=	3826	36,1
Annual Heating Demand QH	Q_L - Q_G	=	1279	12

	kWh/(m²a)		(Yes/No)
Limiting Value	15	Requirement met?	yes


Heating energy balance
Heat flows [kWh/(m²a)]
60
50
40
30
20
10
0
4,0
12,2
3,6
15,3
0,0
2,7
4,3
0,0
10,0
0,0
29,1
11,0
12,1
0,0
Losses
Gains
passive solar gains
internal gains
Annual Heating Demand
Thermal bridge credit
not useful heat gains
Ventilation
Exterior Door
Windows
Floor slab / basement ceiling
Roof/Ceiling - Ambient
Exterior Wall - Ground
Exterior Wall - Ambient
Thermal Bridge Heat Loss

Annex 1.1.11: “Monthly Method“ Worksheet

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND MONTHLY METHOD

(This page displays the sums of the monthly method over the heating period)

Climate:	PL - Strefa II (Poznan/Pila)	Interior Temperature:	20 °C
Building:	Passive House	Building Type/Use:	Dwelling
Spec. Capacity:	132 Wh/(m²K) (Enter in "Summer" worksheet.)	Treated Floor Area A_{TFA}:	106,1 m²

Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Month. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area
Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	*	88	=	1048	
Exterior Wall - Ground	B		*		*	1,00	*		=		
Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	*	88	=	452	
Floor slab / basement ceiling	B	51,6	*	0,099	*	1,00	*	55	=	280	
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Windows	A	31,1	*	0,585	*	1,00	*	88	=	1604	
Exterior Door	A	5,6	*	0,770	*	1,00	*	88	=	379	
Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	*	88	=	0	
Perimeter TB (length/m)	P		*		*	1,00	*		=		
Ground TB (length/m)	B		*		*	1,00	*		=		
Transmission Heat Losses Q_T									Total	3764	35,5 kWh/(m²a)

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume V_{RAX}	106	*	2,50	=	265

	$n_{V,system}$ 1/h		η^*_{SHX}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi\ fraction}$ 1/h
Effective Air Change Rate Ambient $n_{V,e}$	0,407	*(1-	0%	)*(1-	0,80	)+	0,084	=	0,165
Effective Air Change Rate Ground $n_{V,g}$	0,407	*	0%	*(1-	0,80	)		=	0,000

	V_{RAX} m³		$n_{V,equi\ fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Losses Ambient Q_V	265	*	0,165	*	0,33	*	88	=	1277	12,0
Ventilation Losses Ground $Q_{V,e}$	265	*	0,000	*	0,33	*	55	=	0	0,0
Ventilation Heat Losses Q_V								Total	1277	12,0

		Q_T kWh/a		Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	3764	+	1277	) *	1,0	=	5041	47,5

Orientation of the Area	Reduction Factor See Windows worksheet		g-Value (perp. radiation)		Area m²		Global Radiation kWh/(m²a)		kWh/a	
North	0,49	*	0,50	*	3,1	*	94	=	72	
East	0,49	*	0,50	*	3,5	*	216	=	186	
South	0,58	*	0,50	*	21,3	*	416	=	2568	
West	0,48	*	0,50	*	3,1	*	217	=	164	
Horizontal	0,00	*	0,00	*	0,0	*	323	=	0	
Sum Opaque Areas									31	
Available Solar Heat Gains Q_S								Total	3021	28,5 kWh/(m²a)

	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	212	*	2,1	*	106,1	=	1133	10,7

			kWh/a	kWh/(m²a)
Free Heat Q_F	Q_S + Q_I	=	4154	39,2
Ratio Free Heat to Losses	Q_F / Q_L	=	0,82	
Utilisation Factor Heat Gains η_G		=	85%	
Heat Gains Q_G	η_G * Q_F	=	3537	33,4
Annual Heating Demand QH	Q_L - Q_G	=	1503	14

	kWh/(m²a)		(Yes/No)
Limiting Value	15	Requirement met?	yes

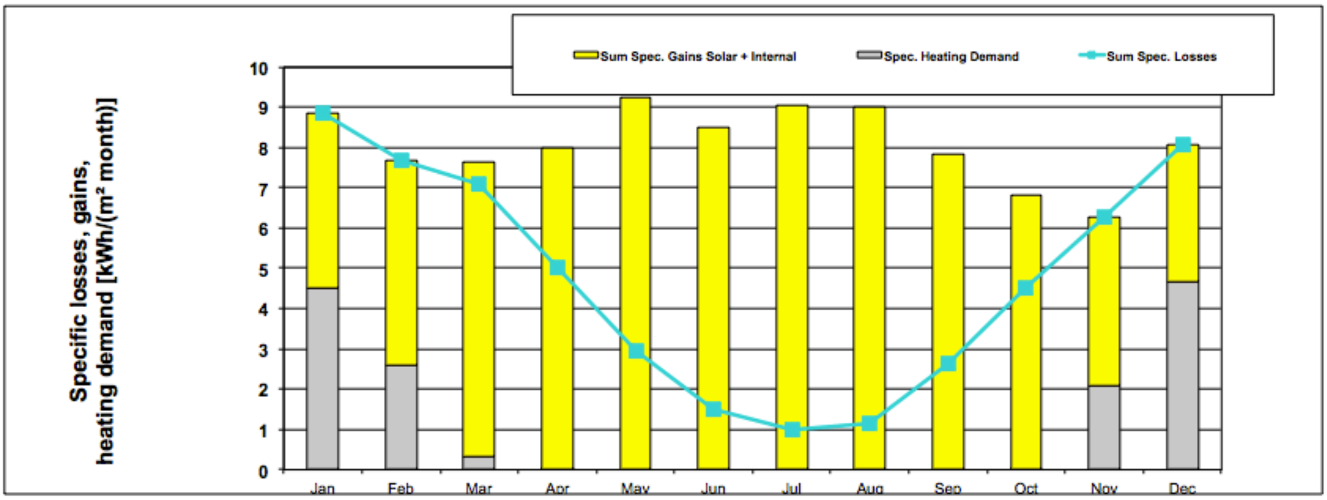
Passive House verification

SPECIFIC ANNUAL HEAT DEMAND
MONTHLY METHOD

Climate: PL - Strefa II (Poznan/Pila)
Building: Passive House

Interior Temperature: 20 °C
Building Type/Use: Dwelling
Treated Floor Area A_{TFA}: 106 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - Ext	16,5	14,3	13,0	9,1	5,1	2,5	1,6	2,0	4,9	8,5	11,8	15,1	104	kKh
Heating Degree Hours - Gro	9,3	9,2	10,1	8,8	7,5	4,9	3,5	2,6	3,2	4,3	5,7	7,7	77	kKh
Losses - Exterior	892	769	702	488	276	134	86	110	263	457	637	815	5630	kWh
Losses - Ground	47	47	51	45	38	25	18	13	16	22	29	39	391	kWh
Sum Spec. Losses	8,9	7,7	7,1	5,0	3,0	1,5	1,0	1,2	2,6	4,5	6,3	8,1	56,8	kWh/m²
Solar Gains - North	5	8	14	23	33	37	36	27	18	11	6	4	222	kWh
Solar Gains - East	11	21	41	60	84	76	81	70	49	30	14	9	546	kWh
Solar Gains - South	265	340	512	543	617	543	593	617	556	482	253	173	5495	kWh
Solar Gains - West	11	18	35	51	68	72	72	66	41	29	11	8	482	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	2	4	7	9	12	12	12	11	8	5	2	2	86	kWh
Internal Heat Gains	166	150	166	160	166	160	166	166	160	166	160	166	1951	kWh
Sum Spec. Gains Solar + In	4,3	5,1	7,3	8,0	9,2	8,5	9,1	9,0	7,8	6,8	4,2	3,4	82,8	kWh/m²
Utilisation Factor	100%	100%	93%	63%	32%	18%	11%	13%	34%	66%	100%	100%	51%	
Annual Heating Demand	479	276	35	0	0	0	0	0	0	0	219	494	1503	kWh
Spec. Heating Demand	**4,5**	**2,6**	**0,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**2,1**	**4,7**	**14,2**	kWh/m²



Annual Heating Demand: Comparison

EN 13790 Monthly Method	**1503**	kWh/a	**14,2**	kWh/(m²a) Reference to habitable area
PHPP, Heating Period Method	**1279**	kWh/a	**12,1**	kWh/(m²a) Reference to habitable area

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total	Heating Period Method
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	219
Ambient Temp.	-2,00	-1,00	2,70	7,60	13,30	16,70	18,00	17,40	13,40	8,80	3,80	-0,10	8,3	3,0
North Radiation	6,0	11,0	19,0	30,0	43,0	48,0	47,0	36,0	23,0	15,0	8,0	5,0	291	100
East Radiation	13,0	24,0	48,0	70,0	97,0	88,0	94,0	81,0	57,0	35,0	16,0	10,0	633	229
South Radiation	43,0	55,0	83,0	88,0	100,0	88,0	96,0	100,0	90,0	78,0	41,0	28,0	890	427
West Radiation	15,0	24,0	47,0	68,0	90,0	95,0	96,0	87,0	55,0	38,0	15,0	10,0	640	229
Hori. Radiation	19,0	36,0	71,0	109,0	156,0	155,0	160,0	136,0	86,0	52,0	23,0	13,0	1016	345
Tsky	-16,11	-14,50	-9,30	-3,12	2,56	7,16	8,61	8,04	3,41	-3,26	-8,95	-12,84	-3,1	
Ground Temp	7,53	6,37	6,45	7,75	9,93	13,21	15,31	16,47	15,58	14,28	12,10	9,63	11,2	9,3

Annex 1.1.12: “Heating Load“ Worksheet

Passive House verification

SPECIFIC SPACE HEATING LOAD

Building:	Passive House	Building Type/Use:	Dwelling
Climate (HL):	PL - Strefa II (Poznan/Pila)	Treated Floor Area A_{TFA}:	106,1 m²
		Interior Temperature:	20 °C

	Design Temperature		Radiation:	North	East	South	West	Horizontal	
Weather Condition 1:	-11,0	°C		10	15	30	15	25	W/m²
Weather Condition 2:	-5,0	°C		5	10	10	10	10	W/m²
Ground Design Temp.	6,4	°C							

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Factor Always 1 (except "X")		TempDiff 1 K		TempDiff 2 K		P_T 1 W		P_T 2 W
1.	Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	*	31,0	or	25,0	=	368	or	297
2.	Exterior Wall - Ground	B		*		*	1,00	*	13,6	or	13,6	=		or	
3.	Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	*	31,0	or	25,0	=	159	or	128
4.	Floor slab / basement ceiling	B	51,6	*	0,099	*	1,00	*	13,6	or	13,6	=	69	or	69
5.		A		*		*	1,00	*	31,0	or	25,0	=		or	
6.		A		*		*	1,00	*	31,0	or	25,0	=		or	
7.		X		*		*	0,75	*	31,0	or	25,0	=		or	
8.	Windows	A	31,1	*	0,585	*	1,00	*	31,0	or	25,0	=	563	or	454
9.	Exterior Door	A	5,6	*	0,770	*	1,00	*	31,0	or	25,0	=	133	or	107
10.	Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	*	31,0	or	25,0	=	0	or	0
11.	Perimeter TB (length/m)	P		*		*	1,00	*	13,6	or	13,6	=		or	
12.	Ground TB (length/m)	B		*		*	1,00	*	13,6	or	13,6	=		or	
13.	House/DU Partition Wall	I		*		*	1,00	*	3,0	or	3,0	=		or	

Transmission Heat Losses P_T — Total = 1293 or 1057

Ventilation System:

Effective Air Volume, V_V: A_{TFA} (m²) 106,1 * Clear Room Height (m) 2,50 = 265 m³

Efficiency of Heat Recovery of the Heat Exchanger η_{HR}: 80% — Heat Recovery Efficiency SHX: 0% — Efficiency SHX: η_{SHX} 1: 0% or η_{SHX} 2: 0%

	$n_{V,Res}$ (Heating Load) 1/h		$n_{V,system}$ 1/h		Φ_{HR}		Φ_{HR}		1/h		1/h
Energetically Effective Air Exchange n_V	0,210	+	0,407	*(1-	0,80	or	0,80	)=	0,291	or	0,291

Ventilation Heating Load P_V

V_L m³		n_L 1/h		n_L 1/h		c_{Air} Wh/(m³K)		TempDiff 1 K		TempDiff 2 K		P_V 1 W		P_V 2 W
265,2	*	0,291	or	0,291	*	0,33	*	31,0	or	25,0	=	790	or	637

Total Heating Load P_L

$P_T + P_V$ = P_L 1: 2084 W or P_L 2: 1694 W

	Orientation the Area	Area m²		g-Value (perp. radiation)		Reduction Factor (see Windows worksheet)		Radiation 1 W/m²		Radiation 2 W/m²		P_S 1 W		P_S 2 W
1.	North	3,1	*	0,5	*	0,5	*	10	or	5	=	8	or	4
2.	East	3,5	*	0,5	*	0,5	*	15	or	10	=	13	or	9
3.	South	21,3	*	0,5	*	0,6	*	30	or	10	=	185	or	62
4.	West	3,1	*	0,5	*	0,5	*	15	or	10	=	11	or	8
5.	Horizontal	0,0	*	0,0	*	0,4	*	25	or	10	=	0	or	0

Solar heating power P_S — Total = 217 or 82

Internal heating power P_I

Spec. Power (W/m²) 1,6 * A_{TFA} (m²) 106 = P_I 1: 170 W or P_I 2: 170 W

Heating power (gains) P_G

$P_S + P_I$ = P_G 1: 387 W or P_G 2: 251 W

$P_L - P_G$ = 1697 or 1443

Heating Load P_H = 1697 W

Specific Heating Load P_H / A_{TFA} = 16,0 W/m²

Input Max. Supply Air Temperature: 40 °C

Max. Supply Air Temperature $\vartheta_{Supply,Max}$: 40 °C — Supply Air Temperature Without Heating $\vartheta_{Supply,Min}$: 13,8 °C / 15,0 °C

For Comparison: Heating Load Transportable by Supply Air. $P_{Supply Air,Max}$ = 932 W specific: 8,8 W/m²

Supply Air Heating Sufficient? (Yes/No): No

Annex 1.1.12: "Heating Load" Worksheet

Passive House verification

SUMMER

Climate: PL - Strefa II (Poznan/Pila)
Building: Passive House

Interior Temperature: 20 °C
Building Type/Use: Dwelling
Treated Floor Area A_{TFA}: 106,1 m²

Spec. Capacity: 132 Wh/K pro m² TFA
Overheating limit: 25 °C

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Red. Factor $f_{T,Summer}$		H_{Summer} Heat Conductance
1.	Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	=	11,9
2.	Exterior Wall - Ground	B		*		*	1,00	=	
3.	Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	=	5,1
4.	Floor slab / basement ce	B	51,6	*	0,099	*	1,00	=	5,1
5.		A		*		*	1,00	=	
6.		A		*		*	1,00	=	
7.		X		*		*	0,75	=	
8.	Windows	A	31,1	*	0,585	*	1,00	=	18,2
9.	Exterior Door	A	5,6	*	0,770	*	1,00	=	4,3
10.	Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	=	0,0
11.	Perimeter TB (length/m)	P		*		*	1,00	=	
12.	Ground TB (length/m)	B		*		*	1,00	=	

Exterior Thermal Transmittance, $H_{T,e}$ 39,5 W/K
Ground Thermal Transmittance, $H_{T,g}$ 5,1 W/K

Heat Recovery Efficiency η_{HR} 80%
SHX Efficiency η^*_{SHX} 0%

Effective Air Volume V_V: A_{TFA} (m²) 106,1 * Clear Room Height (m) 2,50 = 265 m³

Summer Ventilation continuous ventilation to provide sufficient indoor air quality

Air Change Rate by Natural (Windows & Leakages) or Exhaust-Only Mechanical Ventilation, Summer: 0,23 1/h

Mechanical Ventilation Summer: 0,45 1/h   with HR (check if applicable)

	$n_{L,nat}$ 1/h		$n_{V,system}$ 1/h		Φ_{HR}		$n_{V,Rest}$ 1/h		1/h
Energetically Effective Airchange Rate n_V	0,230	+	0,450	* (1 -	0,000	) +	0,000	=	0,680

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		
Ventilation Transm. Ambient $H_{V,e}$	265	*	0,680	*	0,33	=	59,5 W/K
Ventilation Transm. Ground $H_{V,g}$	265	*	0,000	*	0,33	=	0,0 W/K

Additional Summer Ventilation for Cooling   Temperature amplitude summer 10,6 K

Select: x Window Night Ventilation, Manual
Mechanical, Automatically Controlled Ventilation

Corresponding Air Change Rate 0,16 1/h
(for window ventilation: at 1 K temperature difference indoor - outdoor)

Minimum Acceptable Indoor Temperature 22,0 °C

	Orientation of the Area	Angle Factor Summer		Shading Factor Summer		Dirt		g-Value (perp. radiation)		Area m²		Portion of Glazing		Aperture m²
1.	North	0,9	*	0,78	*	0,95	*	0,50	*	3,1	*	77%	=	0,8
2.	East	0,9	*	0,79	*	0,95	*	0,50	*	3,5	*	80%	=	0,9
3.	South	0,9	*	0,63	*	0,95	*	0,50	*	21,3	*	90%	=	5,2
4.	West	0,9	*	0,79	*	0,95	*	0,50	*	3,1	*	77%	=	0,8
5.	Horizontal	0,9	*	1,00	*	0,95	*	0,00	*	0,0	*	0%	=	0,0
6.	Sum Opaque Areas													0,2

Solar Aperture   Total 7,9   0,07 m²/m²

Internal Heat Gains Q_I   Specif. Power q_I (W/m²) 2,10 * A_{TFA} (m²) 106 = 223 W   2,1 W/m²

Frequency of Overheating $h_{\vartheta > \vartheta_{max}}$ **6,8%** **at the overheating limit ϑ_{max} = 25 °C**

If the "frequency over 25°C" exceeds 10%, additional measures to protect against summer heat waves are necessary.

	Solar Load kWh/d		1/k		Spec. Capacity Wh/(m²K)		A_{TFA} m²		
Daily Temperature Swing due to Solar Load	39,5	*	1000	/ (	132	*	106	) =	2,8 K

Annex 1.1.14: “Shading-S“ Worksheet

Passive House verification

CALCULATING SUMMER SHADING FACTORS

Climate: PL - Strefa II (Poznan/Pila)

Building: Passive House

Latitude: 52,42

Summer

Orientation	Glazing area m²	Summer shading factor r_s
North	2,42	78%
East	2,79	79%
South	19,25	63%
West	2,42	79%
Horizontal	0,00	100%

Results from the Summer worksheet:
Frequency of Overheating $h_{\theta > \theta max}$ **6,8%**

														Input Field				
														Summer	Summer			
Quantity	Description:	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing Width	Glazing Height	Glazing Area	Height of the Shading Object	Horizontal Distance	Window Reveal Depth	Distance from Glazing Edge to Reveal	Overhang Depth	Distance from Upper Glazing Edge to Overhang	Additional Shading Reduction Factor (Summer)	Reduction factor z for temporary sun protection	Horizontal Shading Reduction Factor	Reveal Shading Reduction Factor	Overhang Shading Reduction Factor	Total Summer Shading Reduction Factor
		Degrees	Degrees			m		m	m	m	m	m	m	%	%	%	%	%	%
					w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}	z	r_H	r_R	r_O	r_S
1	South	180	90	South	1,88	1,33	2,5	0,00	0,00	0,05	0,08	0,00	0,00	80%	79%	100%	99%	100%	62%
1	South	180	90	South	3,18	2,23	7,1	0,00	0,00	0,05	0,08	0,00	0,00	80%	79%	100%	99%	100%	63%
2	North	0	90	North	1,28	0,48	1,2	0,00	0,00	0,05	0,08	0,00	0,00	80%		100%	98%	100%	78%
1	North	0	90	North	0,88	1,33	1,2	0,00	0,00	0,05	0,08	0,00	0,00	80%		100%	97%	100%	78%
2	East	90	90	East	0,88	1,33	2,4	0,00	0,00	0,05	0,08	0,00	0,00	80%		100%	98%	100%	79%
1	East	90	90	East	0,88	0,48	0,4	0,00	0,00	0,05	0,08	0,00	0,00	80%		100%	98%	100%	79%
2	West	270	90	West	1,28	0,48	1,2	0,00	0,00	0,05	0,08	0,00	0,00	80%		100%	99%	100%	79%
1	West	270	90	West	0,88	1,33	1,2	0,00	0,00	0,05	0,08	0,00	0,00	80%		100%	98%	100%	79%
1	South	180	90	South	1,88	1,33	2,5	0,00	0,00	0,05	0,08	0,00	0,00	80%	79%	100%	99%	100%	62%
1	South	180	90	South	3,18	2,23	7,1	0,00	0,00	0,05	0,08	0,00	0,00	80%	79%	100%	99%	100%	63%

Annex 1.1.15: "SummVent" Worksheet

Passive House verification

SUMMER VENTILATION

Building: Passive House

Building Type/Use: Dwelling

Building Volume: 265 m³

Description		Day GF S	Day GF E	Day 1F S	Night 1F S	Night 1F E		
	Fraction of Opening Duration	50%	50%	50%	70%	70%		
Climate Boundary Conditions								
	Temperature Diff Interior - Exterior	4	4	4	1	1		K
	Wind Velocity	1	1	1	0	0		m/s

Note: for summer night ventilation please set a temperature difference of 1 K and a wind velocity of 0 m/s otherwise the cooling effects of the night ventilation will be overestimated!

Window Group 1								
	Quantity	1	1	1	1	1		
	Clear Width	1,84	0,84	1,84	1,84	0,84		m
	Clear Height	1,29	0,44	1,29	1,29	1,29		m
	Tilting Windows?	x	x	x	x	x		
	Opening Width (for tilting windows)	0,050	0,050	0,050	0,050	0,050		m
Window Group 2 (Cross Ventilation)								
	Quantity			1	1	1		
	Clear Width			0,84	0,84	0,84		m
	Clear Height			1,29	1,29	1,29		m
	Tilting Windows?			x	x	x		
	Opening Width (for Tilting Windows)			0,050	0,050	0,050		m
	Difference in Height to Window 1			0,00	0,00	0,00		m

Single-Sided Ventilation 1 - Airflow Volume	29	7	29	14	11	0	m³/h
Single-Sided Ventilation 2 - Airflow Volume	0	0	23	11	11	0	m³/h
Cross Ventilation Airflow Volume	29	7	88	25	22	0	m³/h
Contribution to Air Change Rate	0,05	0,01	0,17	0,06	0,06	0,00	1/h

Summary of Summer Ventilation Distribution

Description Ventilation Type	Daily Average Air Change Rate	
Nighttime Window Ventilation	0,16	1/h
Daytime Window Ventilation	0,23	1/h
		1/h

Annex 1.1.16: “Cooling“ Worksheet

Passive House verification

SPECIFIC USEFUL COOLING DEMAND MONTHLY METHOD

(This page displays the sums of the monthly method over the cooling period))

Climate: PL - Strefa II (Poznan/Pila)
Building: Passive House
Spec. Capacity: 132 Wh/(m²K) (Enter in Summer worksheet.)

Interior Temperature Summer: 25 °C
Building Type/Use: Dwelling
Treated Floor Area A_{TFA}: 106,1 m²

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Mon. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area
1.	Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	*	47	=	556	
2.	Exterior Wall - Ground	B		*		*	1,00	*		=		
3.	Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	*	47	=	240	
4.	Floor slab / basement ceilin	B	51,6	*	0,099	*	1,00	*	52	=	267	
5.		A		*		*	1,00	*		=		
6.		A		*		*	1,00	*		=		
7.		X		*		*	0,75	*		=		
8.	Windows	A	31,1	*	0,585	*	1,00	*	47	=	851	
9.	Exterior Door	A	5,6	*	0,770	*	1,00	*	47	=	201	
10.	Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	*	47	=	0	
11.	Perimeter TB (length/m)	P		*		*	1,00	*		=		
12.	Ground TB (length/m)	B		*		*	1,00	*		=		

Transmission Losses Q_T (Negative: Heat Loads) Total 2115 kWh/a; 19,9 kWh/(m²a)

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume V_V	106	*	2,50	=	265

	Heat Transfer Coeffi W/K		G_t kKh/a		kWh/a	kWh/(m²a)
Exterior	59,5	*	47	=	2785	26,3
Ground	0,0	*	69	=	0	0,0

Additional Summer Ventilation

Select:
x Window Night Ventilation, Manual
Mechanical, Automatically Controlled Ventilation

Corresponding Air Change Rate 0,16 1/h
(for window ventilation: at 1 K temperature difference indoor - outdoor)
Minimum Acceptable Indoor Temperature 22,0 °C

Heat Losses Summer Ventilation 1804 kWh/a; 17,0 kWh/(m²a)

	$Q_{L,ext}$ kWh/a		$Q_{L,ground}$ kWh/a		$Q_{L,summer}$ kWh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	2785	+	0	+	1804	=	4589	43,3

	Q_T kWh/a		Q_V kWh/a		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	2115	+	4589	=	6704	63,2

	Orientation of the Area	Reduction Factor		g-Value (perp. radiation)		Area m²		Global Radiation kWh/(m²a)		kWh/a
1.	North	0,52	*	0,50	*	3,1	*	227	=	184
2.	East	0,54	*	0,50	*	3,5	*	487	=	457
3.	South	0,48	*	0,50	*	21,3	*	562	=	2895
4.	West	0,52	*	0,50	*	3,1	*	491	=	401
5.	Horizontal	0,40	*	0,00	*	0,0	*	802	=	0
6.	Sum Opaque Areas									64

Available Solar Heat Gains Q_S Total 4001 kWh/a; 37,7 kWh/(m²a)

	kh/d		Length Heat. Period d/a		Spec. Power q W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	183	*	2,1	*	106,1	=	978	9,2

Sum Heat Loads Q_F Q_S + Q_I = 4980 kWh/a; 46,9 kWh/(m²a)

Ratio of Losses to Free Heat Gains Q_L / Q_F = 1,35

Utilisation Factor Heat Losses η_G = 66%

Useful Heat Losses $Q_{V,n}$ η_G * Q_L = 4534 kWh/a; 42,8 kWh/(m²a)

Useful Cooling Demand Q_K Q_F - $Q_{V,n}$ = 445 kWh/a; 4 kWh/(m²a)

Limiting Value 15 kWh/(m²a) **Requirement met?** (Yes/No) yes

Passive House verification

SPECIFIC USEFUL COOLING DEMAND MONTHLY METHOD

Climate: PL - Strefa II (Poznan/Pila)
Building: Passive House

Interior Temperature: 25 °C
Building Type/Use: Dwelling
Treated Floor Area A_{TFA}: 106 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - Ext	20,2	17,5	16,7	12,6	8,8	6,0	5,3	5,7	8,4	12,1	15,3	18,8	147	kKh
Heating Degree Hours - Grd	13,0	12,5	13,8	12,4	11,2	8,5	7,2	6,3	6,8	8,0	9,3	11,4	120	kKh
Losses - Exterior	1997	1737	1650	1247	868	597	522	566	833	1201	1519	1856	14593	kWh
Losses - Ground	66	64	70	63	57	43	37	32	35	41	47	58	614	kWh
Losses Summer Ventilation	52	80	226	394	349	251	231	242	335	452	258	122	2995	kWh
Sum Spec. Heat Losses	19,9	17,7	18,4	16,1	12,0	8,4	7,4	7,9	11,3	16,0	17,2	19,2	171,6	kWh/m²
Solar Load North	5	9	15	24	35	39	38	29	19	12	6	4	236	kWh
Solar Load East	12	23	45	66	91	83	88	76	53	33	15	9	594	kWh
Solar Load South	221	283	428	453	515	453	495	515	464	402	211	144	4585	kWh
Solar Load West	12	20	38	56	74	78	78	71	45	31	12	8	523	kWh
Solar Load Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Load Opaque	2	4	7	9	12	12	12	11	8	5	2	2	86	kWh
Internal Heat Gains	166	150	166	160	166	160	166	166	160	166	160	166	1951	kWh
Sum Spec. Loads Solar + In	3,9	4,6	6,6	7,2	8,4	7,8	8,3	8,2	7,1	6,1	3,8	3,1	75,2	kWh/m²
Utilisation Factor Losses	20%	26%	36%	45%	69%	86%	75%	92%	62%	38%	22%	16%	42%	
Useful Cooling Energy Dem	0	0	0	0	10	53	282	97	3	0	0	0	445	kWh
Spec. Cooling Demand	**0,0**	**0,0**	**0,0**	**0,0**	**0,1**	**0,5**	**2,7**	**0,9**	**0,0**	**0,0**	**0,0**	**0,0**	**4,2**	kWh/m²

Temperature Amplitude Summer 10,6 K

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total
Days	31	28	31	30	31	30	31	31	30	31	30	31	365
Ambient Temp.	-2,00	-1,00	2,70	7,60	13,30	16,70	18,00	17,40	13,40	8,80	3,80	-0,10	8,3
North Radiation	6,0	11,0	19,0	30,0	43,0	48,0	47,0	36,0	23,0	15,0	8,0	5,0	291
East Radiation	13,0	24,0	48,0	70,0	97,0	88,0	94,0	81,0	57,0	35,0	16,0	10,0	633
South Radiation	43,0	55,0	83,0	88,0	100,0	88,0	96,0	100,0	90,0	78,0	41,0	28,0	890
West Radiation	15,0	24,0	47,0	68,0	90,0	95,0	96,0	87,0	55,0	38,0	15,0	10,0	640
Hori. Radiation	19,0	36,0	71,0	109,0	156,0	155,0	160,0	136,0	86,0	52,0	23,0	13,0	1016
Tsky	-16,11	-14,50	-9,30	-3,12	2,56	7,16	8,61	8,04	3,41	-3,26	-8,95	-12,84	-3,1
Ground Temp	7,53	6,37	6,45	7,75	9,93	13,21	15,31	16,47	15,58	14,28	12,10	9,63	11,2

Annex 1.1.17: "Cooling Load" Worksheet

Passive House verification

COOLING LOAD

Building:	Passive House	Building Type/Use:	Dwelling	Interior Temperature:	25 °C
Spec. Capacity:	132 Wh/(m²K) (Enter in "Summer" worksheet.)	Treated Floor Area A_{TFA}:	106,1 m²		
		Climate (Cooling Load):	PL - Strefa II (Poznan/Pila)		

	Ambient Air	Sky	Ground	Radiation:	North	East	South	West	Horizontal	
Design Temperature:	25,0 °C	15,7 °C	16,5 °C		110	230	220	220	350	W/m²

	Building Elements	Temperature Zone	Area m²		U-Value W/(m²K)		Factor Always 1 (except "X")		TempDiff K		W
1.	Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	*	0,0	=	0
2.	Exterior Wall - Ground	B		*		*	1,00	*	-8,5	=	
3.	Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	*	0,0	=	0
4.	Floor slab / basement cei	B	51,6	*	0,099	*	1,00	*	-8,5	=	-43
5.		A		*		*	1,00	*	0,0	=	
6.		A		*		*	1,00	*	0,0	=	
7.		X		*		*	0,75	*	0,0	=	
8.	Windows	A	31,1	*	0,585	*	1,00	*	0,0	=	0
9.	Exterior Door	A	5,6	*	0,770	*	1,00	*	0,0	=	0
10.	Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	*	0,0	=	0
11.	Perimeter TB (length/m)	P		*		*	1,00	*	-8,5	=	
12.	Ground TB (length/m)	B		*		*	1,00	*	-8,5	=	
13.	House/DU Partition Wall	I		*		*	1,00	*	3,0	=	
			$L_{ambient}$ W/K		TempDiff K		L_{Sky} W/K		TempDiff K		
14.	Radiation Correction		-0,9	*	0,0	+	0,9	*	-9,3	=	-8

Transmission Heat Losses P_T — Total = **-52**

Ventilation System:

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume, V_V	106,1	*	2,50	=	265

	Vent. Transm. W/K		TempDiff K		W
Exterior	59,5	*	0,0	=	0
Ground	0,0	*	-8,5	=	0

Additional Summer Ventilation:

x	Window Night Ventilation, Manual	Corresponding Air Change Rate	0,16 1/h
	Mechanical, Automatically Controlled Ventilation	Minimum Indoor Temperature	22,0 °C

		kWh/d		kWh/d		W
Heat Removal Cooling Design Day (from Cooling worksheet)	Window Ventilation	-2,6	/	0,024	=	-108
	Automatic Night Ventilation	0,0	/	0,024	=	0

Ventilation Heat Load P_V — Total = W **-108**

	Orientation of the Area	Area m²		g-Value (perp. radiation)		Reduction Factor		Radiation W/m²		P_S W
1.	North	3,1	*	0,5	*	0,52	*	110	=	89
2.	East	3,5	*	0,5	*	0,54	*	230	=	216
3.	South	21,3	*	0,5	*	0,48	*	220	=	1133
4.	West	3,1	*	0,5	*	0,52	*	220	=	180
5.	Horizontal	0,0	*	0,0	*	0,40	*	350	=	0
6.	Sum Opaque Areas									29

Heat Gain - Solar Heat Load, P_S — Total = **1647**

	Spec. Power W/m²		A_{TFA} m²		P_I W
Internal Heat Load P_I	3,1	*	106	=	**329**

Cooling Load P_C — $P_T + P_V + P_S + P_I$ = **1816** **W**

Specific Maximum Cooling Load P_C / A_{EB} = **17,1** **W/m²**

Minimal supply air temperature 4 °C — Supply air temperature without cooling $\vartheta_{Supply,Min}$ 25,0 °C

Cooling capacity that is transportable through the supply air $P_{SupplyAir,Max}$ = 811 W

specific = 7,6 W/m²

Air conditioning over the supply air possible? (yes/no) **no**

	Solar Load W		Time h/d		Spec. Capacity Wh/(m²K)		A_{TFA} m²			
Daily Temperature Swing due to Solar Load	1647,1	*	24	/ (	132	*	106	) =	**2,8**	**K**

Annex 1.1.18: "DHW + Distribution" Worksheet

Passive House verification

HEAT DISTRIBUTION AND DHW SYSTEM

Building:	Passive House	
Interior Temperature:	20	°C
Building Type/Use:	Dwelling	
Treated Floor Area A_{TFA}:	106	m²
Occupancy:	4,0	Pers
Number of Residences:	1	
Annual Heating Demand qHeating	1503	kWh/a
Length of Heating Period:	219	d
Average heating load Pave:	0,3	kW
Marginal Utilisability of Additional Heat Gains:	59%	

				Parts: Warm Region 1	Cold Region 2	3	Total		
Space Heat Distribution									
Length of Distribution Pipes	L_H	(Project)		41,80				m	
Heat Loss Coefficient per m Pipe	Ψ	(Project)		0,344				W/(mK)	
Temperature of the Room Through Which the Pipes Pass	ϑ_X	Mechanical Room		20				°C	
Design Flow Temperature	ϑ_{dist}	Flow, Design Value		55,0				°C	
Design System heating load	$P_{heating}$	(exist./calc.)		1,7				kW	
Flow Temperature Control (check)				x					
Design Return Temperature	ϑ_R		$=0.714\cdot(\vartheta_{dist}-20)+20$	45,0				°C	
Annual Heat Emission per m of Plumbing	q^*_{HL}		$=\Psi\,(\vartheta_m-\vartheta_X)\,t_{Heating}\cdot 0.024$	14			Total 1,2,3	kWh/(m·a)	
Possible Utilization Factor of Released Heat	η_G			59%				-	
Annual Losses	Q_{HL}		$=L_H\cdot q^*_{HL}\cdot(1-\eta_G)$	242	0	0	242	kWh/a	
Specif. Losses	q_{HL}		$=\Sigma Q_{HL}\,/\,A_{TFA}$					kWh/(m²a)	2,3
'Performance ratio of heat distribution	$e_{a,HL}$		$=(q_H+q_{HL})\,/\,q_H$				116%	-	
DHW: Standard Useful Heat									
DHW Consumption per Person and Day (60 °C)	V_{DHW}	(Project or Average Value 25 Litres/P/d)					25,0	Litre/Person/d	
Average Cold Water Temperature of the Supply	ϑ_{DW}	Temperature of Drinking Water (10°)					9,3	°C	
DHW Non-Electric Wash and Dish		(Electricity worksheet)					304	kWh/a	
Useful Heat - DHW	Q_{DHW}						2452	kWh/a	
Specif. Useful Heat - DHW	q_{DHW}		$=Q_{DHW}\,/\,A_{TFA}$					kWh/(m²a)	23,1

DHW Distribution and Storage				Warm Region	Cold Region		Total		
Length of Circulation Pipes (Flow + Return)	L_{HS}	(Project)						m	
Heat Loss Coefficient per m Pipe	Ψ	(Project)						W/m/K	
Temperature of the Room Through Which the Pipes Pass	ϑ_X	Mechanical Room		20				°C	
Design Flow Temperature	ϑ_{dist}	Flow, Design Value						°C	
Daily circulation period of operation.	td_{Circ}	(Project)						h/d	
Design Return Temperature	ϑ_R		$=0.875\cdot(\vartheta_{dist}-20)+20$					°C	
Circulation period of operation per year	t_{Circ}		$=365\,td_{Circ}$					h/a	
Annual Heat Released per m of Pipe	q^*_Z		$=\Psi\,(\vartheta_m-\vartheta_X)\,t_{Circ}$					kWh/m/a	
Possible Utilization Factor of Released Heat	$\eta_{G DHW}$		$=t_{heating}/365d\cdot\eta_G$					-	
Annual Heat Loss from Circulation Lines	Q_Z		$=L_{HS}\cdot q^*_Z\cdot(1-\eta_{G DHW})$				0	kWh/a	
				Please fill in ce					
Total Length of Individual Pipes	L_U	(Project)		33,16				m	
Exterior Pipe Diameter	d_{U_Pipe}	(Project)		0,018				m	
Heat loss per tap opening	$q_{individual}$		$=(c_{pH2O}V_{H2O}+c_{pMat}V_{Mat})(\vartheta_{dist}-\vartheta_X)$	-0,1418				kWh/tap opening	
Amount of tap openings per year	n_{tap}		$=n_{Pers}\cdot 3\cdot 365\,/\,n_{LU}$	4380				Tap openings per year	
Annual Heat Loss	q_U		$=n_{tap}\cdot q_{individual}$	-621				kWh/a	
Possible Utilization Factor of Released Heat	η_{G_U}		$=t_{heating}/8760\cdot\eta_G$	36%				-	
Annual Heat Loss of Individual Pipes	Q_U		$=q_U\cdot(1-\eta_{G\_U})$	-399			-399	kWh/a	
							Total 1,2,3		
Average Heat Released From Storage	P_S							W	
Possible Utilization Factor of Released Heat	η_{G_S}		$=t_{heating}/8760\cdot\eta_G$						
Annual Heat Losses from Storage	Q_S		$=P_S\cdot 8.760\text{ kh}\cdot(1-\eta_{G\_S})$				0	kWh/a	
							Total 1,2,3		
Total Heat Losses of the DHW System	Q_{WL}		$=Q_Z+Q_U+Q_S$				-399	kWh/a	
Specif. Losses of the DHW System	q_{WL}		$=Q_{WL}\,/\,A_{TFA}$					kWh/(m²a)	-3,8
Performance ratio DHW-distribution + storage	$e_{a,WL}$		$=(q_{TWW}+q_{WL})\,/\,q_{TWW}$				83,7%	-	
Total Heating Demand of DHW system	Q_{gDHW}		$=Q_{DHW}+Q_{WL}$				2053	kWh/a	
Total Spec. Heating Demand of DHW System	q_{gDHW}		$=Q_{gDHW}\,/\,A_{TFA}$					kWh/(m²a)	19,4

Secondary Calculation Storage Losses

Specific Heat Losses Storage (total)	3,0	W/K
Typical Temperature DHW	55	°C
Room Temperature	20	°C
Total Storage Heat Losses	105	W

Annex 1.1.19: “Solar DHW“ Worksheet

Passive House verification

SOLAR HOT WATER GENERATION

Building: Passive House

Building Type/Use: Dwelling

Treated Floor Area A_{TFA}: 106,1 m²

Solar Fraction with DHW demand including washing and dish-washing

Heating Demand DHW	q_{DHW}	2053	kWh/a	from DHW+Distribution worksheet
Latitude:		52,4	°	from Climate Data worksheet
Selection of collector from list (see below):		8	Selection:	8 Vacuum Tube Collector
Solar Collector Area		4,24	m²	
Deviation from North		180	°	
Angle of Inclination from the Horizontal		45	°	
Height of the Collector Field		1,98	m	
Height of Horizon	h_{Hori}		m	
Horizontal Distance	a_{Hori}		m	
Additional Reduction Factor Shading	r_{other}	100%	%	
Occupancy		4,0	Persons	
Specific Collector Area		1,1	m²/Pers	

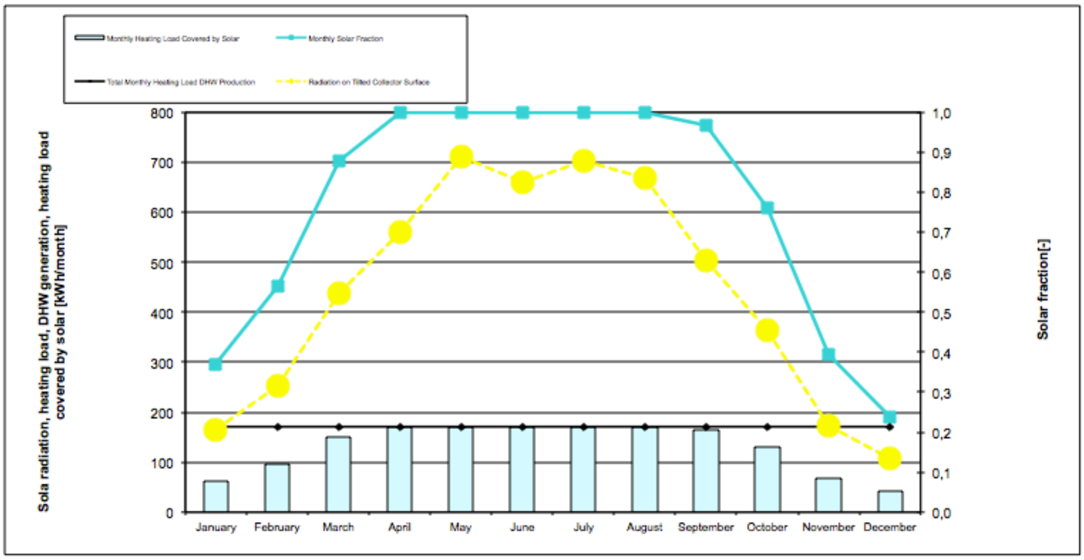
Estimated Solar Fraction of DHW Production 76%

Solar Contribution to Useful Heat 1570 kWh/a 15 kWh/(m²a)

Secondary Calculation of Storage Losses

Selection of DHW storage from list (see below):	11	Selection:	11 Stratified Solar Storage
Total Storage Volume	391	litre	
Volume Standby Part (above)	117	litre	
Volume Solar Part (below)	274	litre	
Specific Heat Losses Storage (total)	2,9	W/K	
Typical Temperature DHW	55	°C	
Room Temperature	16	°C	
Storage Heat Losses (Standby Part Only)	27	W	
Total Storage Heat Losses	112	W	

Monthly Solar Fraction	January	February	March	April	May	June	July	August	September	October	November	December	
Radiation on Tilted Collector Surface	163	253	439	561	712	659	703	668	503	363	174	108	kWh/Month
Monthly Solar Fraction	0,37	0,57	0,88	1,00	1,00	1,00	1,00	1,00	0,97	0,76	0,40	0,24	-
Total Monthly Heating Load DHW Production	171	171	171	171	171	171	171	171	171	171	171	171	kWh/Month
Monthly Heating Load Covered by Solar	63	97	150	171	171	171	171	171	166	130	68	41	kWh/Month



Annex 1.1.20: “Electricity“ Worksheet

Passive House verification

ELECTRICITY DEMAND

Building: Passive House

# Households	1	HH
Persons	4,0	P
Living Area	106	m²
Annual Heating Demand	14	kWh/(m²a)

Solar Fraction of DHW Laundry&Dish	55%
Marginal Performance Ratio DHW	111%
Marginal Performance Ratio Heating	111%

Prim. Energy Factors:	Electricity	2,6		kWh/kWh
	Natural Gas	1,1		kWh/kWh
Energy Carrier for Space Heating/DHW:			1,1	1,1

Column Nr.	1	2	3		4	5	6	7	8	8a	9	10	11	12	13	14
Application	Used ? (1/0)	Within the Thermal Envelope? (1/0)	Norm Demand		Utilization Factor	Frequency	Reference Quantity	Useful Energy (kWh/a)	Electric Fraction	Non-Electric Fraction	Electricity Demand (kWh/a)	Additional Demand	Marginal Performance Ratio	Solar Fraction	Non-Electric Demand (kWh/a)	Primary Energy-Demand (kWh/a)
Dishwashing	1	1	1,10 kWh/Use		1,00	65 /(P*a)	4,0 P	286	50%		143					372
DHW Connection										50%		0,30	1,11	0,55	93	102
Clothes washing	1	1	1,10 kWh/Use		1,00	57 /(P*a)	4,0 P	251	55%		138					359
DHW Connection										45%		0,05	1,11	0,55	59	65
Clothes drying with:	1	1	3,50 kWh/Use	Residual dampness 0,60	0,88	57 /(P*a)	4,0 P	0	0%		0					0
Clothesline								0		0%			1,00		0	0
Energy consumed by evaporation	1	1	3,13 kWh/Use		0,60	57 /(P*a)	4,0 P	428		100%		0,00	1,11	0,74	122	135
Refrigerating	0	1	0,78 kWh/d		1,00	365 d/a	1 HH	0	100%		0					0
Freezing	0	1	0,88 kWh/d		1,00	365 d/a	1 HH	0	100%		0					0
or combined unit	1	1	1,00 kWh/d		1,00	365 d/a	1 HH	365	100%		365					949
Cooking with:	1	1	0,25 kWh/Use		1,00	500 /(P*a)	4,0 P	500	0%		0					0
Gas										100%					500	550
Lighting	1	1	21 W	Percentage CFLs 80%	1,00	2,90 kh/(P*a)	4,0 P	241	100%		241					627
Consumer electronics	1	1	80 W		1,00	0,55 kh/(P*a)	4,0 P	176	100%		176					458
Small appliances, etc.	1	1	50 kWh		1,00	1,00 /(P*a)	4,0 P	200	100%		200					520
Total aux. electricity								558			558					1450
Other:																
			kWh/a					0			0					0
			kWh/a					0			0					0
			kWh/a					0			0					0
Total								3005 kWh			1821 kWh		DHW Non-Electric - Wash&Dish 304		774 kWh	5586
Specific Demand											17,2 kWh/(m²a)		Non-Renewable Non-Electric DHW Wash&Dish 1,3		7,3 kWh/(m²a)	52,7
Recommended Maximum Value											18					50

Annex 1.1.21: “Auxiliary Electricity“ Worksheet

Passive House verification

AUXILIARY ELECTRICITY

Building: Passive House

1	Living Area	106	m²
2	Heating Period	219	d
3	Air Volume	265	m³
4	Dwelling Units	1	HH
5	Enclosed Volume	531	m³

Operation Vent. System Winter	5,26	kh/a
Operation Vent. System Summer	3,50	kh/a
Air Change Rate	0,41	h^{-1}
Defrosting HX from	-2,0	°C

Primary Energy Factor - Electricity	2,6	kWh/kWh
Annual Space Heating Demand	14	kWh/(m²a)
Boiler Rated Power	15	kW
DHW System Heating Demand	2053	kWh/a
Design Flow Temperature	55	°C

Column Nr.	1	2	3		4	5		6		7	8	9	10	11
Application	Used ? (1/0)	Within the Thermal Envelope? (1/0)	Norm Demand		Utilization Factor	Period of Operation		Reference Size		Electricity Demand (kWh/a)	Available as Interior Heat	Used During Time Period (kh/a)	Internal Heat Source (W)	Primary Energy Demand (kWh/a)
Ventilation System														
Winter Ventilation	1	1	0,42	Wh/m³	0,41 h^{-1}	5,3	kh/a	265,15	m³	238	considered in heat recovery efficiency			619
Summer Ventilation	1	1	0,42	Wh/m³	0,45 h^{-1}	3,5	kh/a	265,15	m³	176	no summer contribution to IHG			457
Defroster HX	1	0	316	W	1,00	0,1	kh/a	1		43	1,0	5,26	0	111
Heating System					Controlled/Uncontrolled (1/0)									
			Enter the Rated Power of the Pump	W	0									
Circulation Pump	0	0	59	W	1,0	5,3	kh/a	1		0	1,0	5,26	0	0
			Boiler Electricity Consumption at 30% Load	W										
Aux. Energy - Heat. Boiler	1	0	55	W	1,00	0,39	kh/a	1		21	1,0	5,26	0	55
Aux. Energy - Wood fired/pellet boiler	0	0	Data entries in worksheet Boiler. Auxiliary energy demand including possible drinking water production.							0	1,0	5,26	0	0
DHW system														
			Enter Average Power Consumption of Pump	W										
Circulation Pump	0	0	28	W	1,00	4,7	kh/a	1		0	0,6	8,76	0	0
			Enter the Rated Power of the Pump	W										
Storage Load Pump DHW	1	1	54	W	1,00	0,1	kh/a	1		7	1,0	5,26	1	19
			Boiler Electricity Consumption at 100% Load	W										
DHW Boiler Aux. Energy	1	0	165	W	1,00	0,0	kh/a	1		5	1,0	5,26	0	14
			Enter the Rated Power of the Solar DHW Pump	W										
Solar Aux Electricity	1	1	38	W	1,00	1,8	kh/a	1		67	0,6	8,76	5	175
Misc. Aux. Electricity														
Misc. Aux. Electricity	0	0		kWh/a	1,00	1,0		1	HH	0	1,0	8,76	0	0
Total										558			6	1450
Specific Demand	kWh/(m²a)		Divide by Living Area:							5,3				13,7

Annex 1.1.22: "Primary Energy Value" Worksheet

Passive House verification

PRIMARY ENERGY VALUE

Building:	Passive House		Building Type/Use:	Dwelling
			Treated Floor Area A_{TFA}:	106 m²
			Space Heating Demand incl. Distribution	16 kWh/(m²a)
			Useful Cooling Demand:	0 kWh/(m²a)

		Final Energy	Primary Energy	Emissions CO_2-Equivalent
		kWh/(m²a)	kWh/(m²a)	kg/(m²a)
Boiler			PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand	*(Project)*	100%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand	*(Project)*	100%	1,1	250
Boiler Type	*(Boiler worksheet)*	Low Temperature Boiler Gas		
Performance Ratio of Heat Generator	*(Boiler worksheet)*	140%		
Annual Energy Demand (without DHW Wash&Dish)	*(Boiler worksheet)*	28,0	30,8	7,0
Non-Electric Demand, DHW Wash&Dish	*(Electricity worksheet)*	1,4	1,6	0,4
Total Heating Oil/Gas/Wood		29,4	32,4	7,4

Annex 1.1.23: “Boiler“ Worksheet

Passive House verification

EFFICIENCY OF HEAT GENERATION (GAS, OIL, WOOD)

Building: Passive House

Building Type/Use: Dwelling

Treated Floor Area A_{TFA}: 106 m²

Covered Fraction of Space Heating Demand		(PE Value worksheet)	100%	
Space Heating Demand + Distribution Losses	Q_H+Q_{HS}:	(DHW+Distribution)	1745	kWh
Solar Fraction for Space Heat	$\eta_{Solar, H}$	(Separate Calculation)	0%	
Effective Annual Heating Demand	$Q_{H,wi}=Q_H*(1-\eta_{Solar, H})$		**1745**	kWh
Space Heating Demand without Distribution Losses	Q_H	(Verification sheet)	1503	kWh
Covered Fraction of DHW Demand		(PE Value worksheet)	100%	
Total Heating Demand of DHW system	Q_{gDHW}	(DHW+Distribution)	2053	kWh
Solar Fraction for DHW	$\eta_{Solar, DHW}$	(SolarDHW worksheet)	76%	

			Project Data		Standard Values		Input field
Design Output	$P_{nominal}$	(Rating Plate)	15	kW	15	kW	
Installation of Boiler (Outdoor: 0, Indoor: 1)			0		0		
Input Values (Oil and Gas Boiler)			Project Data		Standard Values		Input field
Boiler Efficiency at 30% Load	$\eta_{30\%}$	(Manufacturer)	91%		91%		
Boiler Efficiency at Nominal Output	$\eta_{100\%}$	(Manufacturer)	90%		90%		
Standby Heat Loss Boiler at 70 °C	$q_{B,70}$	(Manufacturer)	1,4%		1,4%		
Average Return Temperature Measured at 30% Load	$\vartheta_{30\%}$	(Manufacturer)	40	°C	40		

Length of the Heating Period	t_{HP}	5255	h
Length of DHW Heating Period	t_{DHW}	8760	h

Utilisation Factor Heat Generator Heating Run	$h_{H,g,K} = f_\varphi * \eta_{K'}$	**75%**
Utilisation Factor Heat Generator DHW Run	$h_{TW,g,K} = \eta_{100\%}/f_{\varphi, TW}$	**61%**
Utilisation Factor Heat Generator DHW & Heating	$h_{g,K}$	**71%**

		kWh/a	kWh/(m²a)
Final Energy Demand Space Heating	$Q_{Final, HE} = Q_{H,wi} * e_{H,g,K}$	**2333**	
Final Energy Demand DHW	$Q_{Final, DHW} = Q_{WW,wi} * e_{TW,g,K}$	**788**	
Total Final Energy Demand	$Q_{Final} = Q_{Final,DHW} + Q_{Final,HE}$	**3121**	**29,4**
Annual Primary Energy Demand		**3434**	**32,4**
		kg/a	kg/(m²a)
Annual CO_2-Equivalent Emissions		**780**	**7,4**

Secondary Calculation: Efficiency of the Oil and Gas Boiler:

Design Flow Temperature	ϑ_{flow}	*(DHW+Distribution)*	55	°C
Average Boiler Temperature Space Heating	ϑ_{ba}	*(Table values)*	38	°C
Average Boiler Temperature (Summer) DHW	$\vartheta_{ba,DHW}$	$=35+0.002 \cdot A_{TFA}$	35,2	°C
Standby Heat Loss at Average Boiler Temperature Heating	$q_{B,\vartheta}$	$=q_{B,70} \cdot (\vartheta_{ba}-20)/(70-20)$	0,52%	
Standby Heat Loss at Average Boiler Temperature DHW	$q_{B,J,DHW}$	$=q_{B,70} \cdot (\vartheta_{m,DHW}-20)/(70-20)$	0,44%	
Average Useful Heating Load, DHW	P_{DHW}	$=Q_{WW,W}/t_{TW}$	0,055	kW
Load Fraction Boiler Heating	φ_H	$=Q_{H,wi}/(P_{Nenn} \cdot t_{H2})$	2,2%	
Load Fraction Boiler DHW	φ_{DW}	$=P_{DW}/P_{nominal}$	0,4%	
Heat Loss Factor Heating (Interior / Exterior Installation)	f_c	$=25 \cdot \theta_{B,\vartheta}$ or 1	1,000	
Boiler Efficiency Heating (Interior/Exterior Correction)	$\eta_{k'}$	$=\eta_{30\%}+q_{B,\vartheta} \cdot (1-f_c)/\varphi_H$	90,8%	
Load Factor Boiler (Use and Operating Temp.)	f_φ	$=(1+(1/0.3-1) \cdot q_{B,\vartheta})$ / $(1+(1/\varphi_H-1) \cdot q_{B,\vartheta})$	0,824	
Boiler Efficiency Heating (Condensation Allowance)	$\eta_{k''}$	$=\eta_{k'}+0.003 \cdot (\vartheta_{30\%}-\vartheta_{km}))$	90,8%	
Fraction of Standby Losses Outside of the Heating Period	f_{DW}	$=1-t_{HP}/t_{DHW}$	0,400	
Load Factor Boiler DHW	$f_{\varphi,DW}$	$=1+(1/\varphi_{DHW}-1) \cdot q_{B,\vartheta DHW} \cdot f_{DHW}$	1,474	
Performance Ratio of Heat Generator Space Heat Run	$e_{H,g,K}$	$=1/(f_\varphi \cdot \eta_{k''})$	134%	
Performance Ratio of Heat Generator DHW Run	$e_{DW,g,K}$	$=f_{\varphi,DHW}/\eta_{100\%}$	163%	

Standard Values LT and Condensing Boiler

	Improved gas condensing boiler	Improved oil condensing boile	Condensing boiler gas	Condensing boiler oil	Low Temperature Bo	Low Temperature Boiler Oil	
$\eta_{30\%}$	104,2%	99,2%	99,2%	94,5%	90,8%	90,8%	
$\eta_{100\%}$	95,2%	95,2%	93,2%	93,2%	90,3%	90,3%	
Condensing?	x	x	x	x			
System Design	Average Boiler Temperature [°C]						System Design
70 °C / 55 °C	41	41	41	41	46	46	70 °C / 55 °C
55 °C / 45 °C	35	35	35	35	38	38	55 °C / 45 °C
35 °C / 28 °C	24	24	24	24	26	26	35 °C / 28 °C
Av. Boiler Temp During Test	30	30	30	30	40	40	

Annex 1.1.24: “Climate Data“ Worksheet

Passive House verification

CLIMATE DATA

Standard/Regional Climate: Select here.

Regional climate data

Select region here

N-Europe

Select regional climate here:

PL - Strefa II (Poznan/Pila)

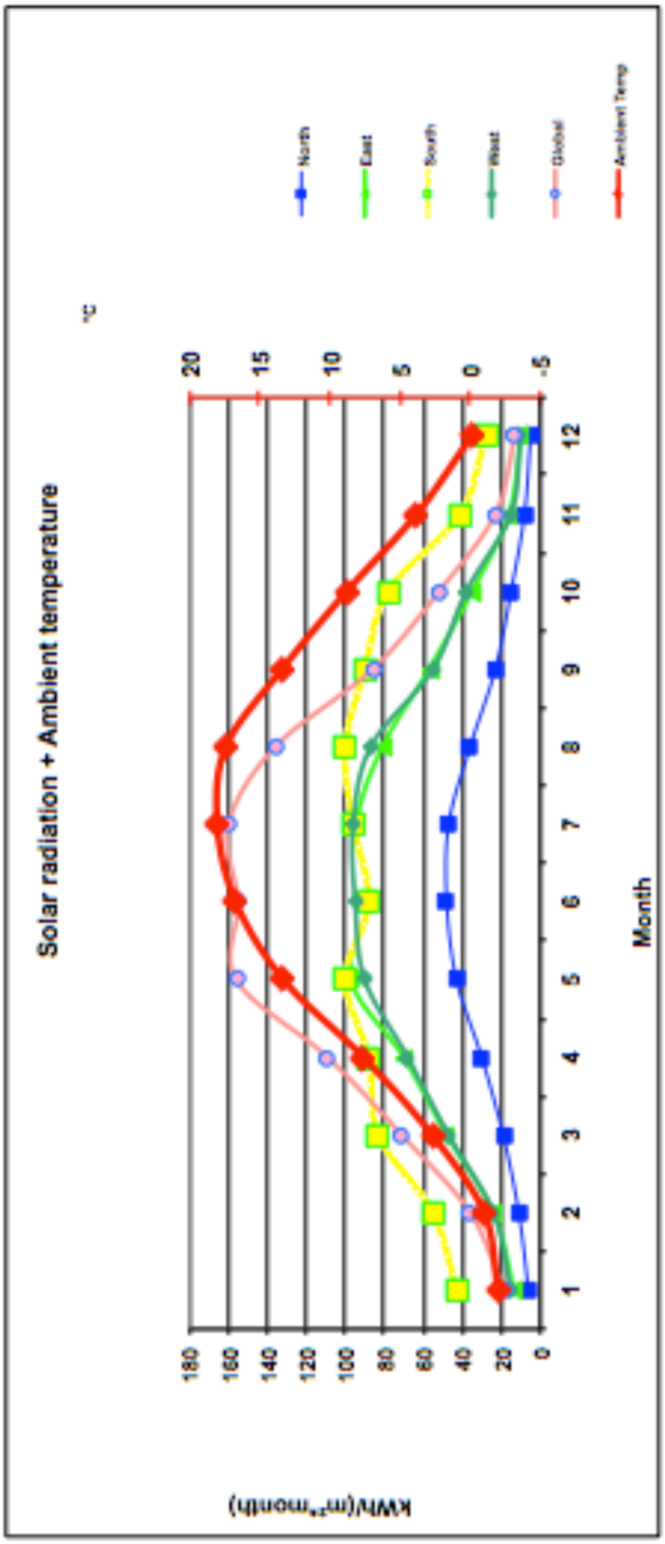
Building:	Passive House	
Use Regional Data?	Yes	
Climate Building	PL - Strefa II (Poznan/Pila)	
Chosen Method for Heating Demand:	Monthly method	
Monthly Data:	PL - Strefa II (Poznan/Pila)	
Annual Data:		
Use Annual Climate Data Set	No	
Results:		
Annual Heating Demand	14,2	kWh/(m²a)
Heating Load	16,0	W/m²

	Transfer to Annual Method	
H_T	219	d/a
G_t	89	kKh/a
North	100	kWh/(m²a)
East	229	kWh/(m²a)
South	427	kWh/(m²a)
West	229	kWh/(m²a)
Horizontal	345	kWh/(m²a)

Parameters for PHPP Calculated Ground Temperatures:	
Phase Shift Months	2,00
Damping	-1,05
Depth m	3,32
Shift of Average Temperature K	1,60

Month	1	2	3	4	5	6
Days	31	28	31	30	31	30
PL - Strefa II (Poznan/Pila)	Latitude:	52,4	Longitude ° East	16,9	Altitude m	97
Ambient Temp	-2,0	-1,0	2,7	7,6	13,3	16,7
North	6	11	19	30	43	48
East	13	24	48	70	97	88
South	43	55	83	88	100	88
West	15	24	47	68	90	95
Global	19	36	71	109	156	155
Dew Point	-3,8	-3,2	-0,5	2,6	6,6	10,4
Sky Temp	-16,1	-14,5	-9,3	-3,1	2,6	7,2
Ground Temp	7,5	6,4	6,4	7,7	9,9	13,2

7	8	9	10	11	12	Heating Load		Cooling Load
31	31	30	31	30	31	Weather 1	Weather 2	Radiation
	Daily Temperature Swing Summer (K)		10,6	Radiation Data:	kWh/(m²*month)	Radiation: W/m²		W/m²
18,0	17,4	13,4	8,8	3,8	-0,1	-11,0	-5,0	25,0
47	36	23	15	8	5	10	5	110
94	81	57	35	16	10	15	10	230
96	100	90	78	41	28	30	10	220
96	87	55	38	15	10	15	10	220
160	136	86	52	23	13	25	10	350
11,7	11,7	9,1	5,8	1,4	-1,8			
8,6	8,0	3,4	-3,3	-9,0	-12,8			15,7
15,3	16,5	15,6	14,3	12,1	9,6	6,4	6,4	16,5


Solar radiation + Ambient temperature
kWh/(m²*month)
°C
Month
180
160
140
120
100
80
60
40
20
0
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
10
11
12
North
East
South
West
Global
Ambient Temp

Annex 1.1.25: “Internal Heat Gains“ Worksheet

Passive House verification

INTERNAL HEAT GAINS

Building: Passive House

Utilisation Pattern: Dwelling | 2,10 W/m²

Type of Values Used: Standard

No entry required | | W/m²

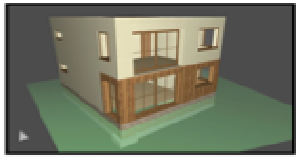
Calculation Internal Heat Household	Persons	4,0	P	Heating Demand	14	kWh/(m²a)
	Living Area	106	m²	Heating Period	219	d/a

Column Nr.	1	2	3		4	5		6		7		8		9		10
Application	Existing (1/0), or number of people	In the Thermal Envelope (1/0)	Norm Consumption		Utilization Factor	Frequency		Useful Energy (kWh/a)		Included in Electricity Balance?		Availability		Used During Time Period (kh/a)		Internal Heat Source (W)
Dishwashing	1	1	1,1	kWh/Use	1,00	65	/(P*a)	286	*			0,30	/	8,76	=	10
Clothes Washing	1	1	1,1	kWh/Use	1,00	57	/(P*a)	251	*			0,30	/	8,76	=	9
Clothes drying with:	1	1	3,5	kWh/Use	0,88	57	/(P*a)	0	*			1,00	/	8,76	=	0
Clothesline		1	0,0					0				0,80				
Energy consumed by evaporation	1	1	-3,1	kWh/Use	0,60	57	/(P*a)	-428	* (1-	0	) *	1,00	/	8,76	=	-49
Refrigerating	0	1	0,8	kWh/d	1,00	365	d/a	0	*			1,00	/	8,76	=	0
Freezing	0	1	0,9	kWh/d	1,00	365	d/a	0	*			1,00	/	8,76	=	0
or Combination	1	1	1,0	kWh/d	1,00	365	d/a	365	*			1,00	/	8,76	=	42
Cooking	1	1	0,3	kWh/Use	1,00	500	/(P*a)	500	*			0,50	/	8,76	=	29
Lighting	1	1	20,8	W	1,00	2,9	kh/(P*a)	241	*			1,00	/	8,76	=	28
Consumer Electronics	1	1	80,0	W	1,00	0,55	kh/(P*a)	176	*			1,00	/	8,76	=	20
Household Appliances/Other	1	1	50,0	kWh	1,00	1,0	/(P*a)	200	*			1,00	/	8,76	=	23
Auxiliary Appliances (cf. Aux Electricity Sheet)															=	6
Other Applications (cf. Electricity Sheet)	0	0,0						0	*			0	/	8,76	=	0
Persons	4	1	80,0	W/P	1,00	8,76	kh/a	2803	*			0,55	/	8,76	=	176
Cold Water	4	1	-5,0	W/P	1,00	8,76	kh/a								=	-20
Evaporation	4	1	-25,0	W/P	1,00	8,76	kh/a	-876	*			1,00	/	8,76	=	-100
Total														W		**172**
Specific Demand														W/m²		**1,62**
Heat Available From Internal Sources										219	d/a			kWh/(m²a)		**8,5**

Annex 1.2: Standard House

Annex 1.2.1: “Verification“ Worksheet

Passive House verification



Building:	Passive House
Street:	Czechoslowacka 6c
Postcode/City:	61-461/Poznan
Country:	Poland
Building Type:	Dwelling
Climate:	PL - Strefa II (Poznan/Pila)
Home Owner(s) / Client(s):	Marta Moskalik
Street:	Czechoslowacka 6c
Postcode/City:	61-461/Poznan
Architect:	Marta Moskalik
Street:	
Postcode/City:	
Mechanical System:	
Street:	
Postcode/City:	

Year of Construction:	2014	Interior Temperature:	20,441	°C
Number of Dwelling Units:	1	Internal Heat Gains:	2,1	W/m²
Enclosed Volume V_e:	530,5			
Number of Occupants:	4,0			

Specific building demands with reference to the treated floor area — use: Monthly method

				Requirements	Fulfilled?*
	Treated floor area	106,1	m²		
Space heating	Annual heating demand	29,08	kWh/(m²a)	15 kWh/(m²a)	no
	Heating load	19	W/m²	10 W/m²	no
Space cooling	Overall specific space cooling demand		kWh/(m²a)	-	-
	Cooling load		W/m²	-	-
	Frequency of overheating (> 25 °C)	26,3	%	-	-
Primary Energy	Space heating and cooling, dehumidification, DHW, household electricity.		kWh/(m²a)	120 kWh/(m²a)	
	DHW, space heating and auxiliary electricity		kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	-
Airtightness	Pressurization test result n_{50}	0,6	1/h	0,6 1/h	yes

* empty field: data missing; '-': no requirement

Calculation electricity / Internal heat gains

Building type: Residential building

Internal heat gains

Utilisation pattern: Dwelling

Type of values used: Standard

Planned number of occupants

4 — Design

Verification — Monthly method

Specific space heating demand, annual method:	28,4	kWh/(m²a)
Specific space heating demand, monthly Method:	29,1	kWh/(m²a)

Reduce cooling/dehumidification demand through passive measures or use 'Cooling Units' worksheet!

Annex 1.2.2: “Areas“ Worksheet

Passive House verification

AREAS DETERMINATION

Building: Passive House | Heating demand 14 kWh/(m²a)

Group Nr.	Area group	Temp. zone	Area	Unit	Comments	Building element overview	Average U-Value [W/(m²K)]
					Summary		
1	Treated Floor Area		106,06	m²	*Living area or useful area within the thermal envelope*		
2	North Windows	A	3,13	m²	Results are from the Windows worksheet.	North Windows	0,649
3	East Windows	A	3,50	m²		East Windows	0,631
4	South Windows	A	21,31	m²		South Windows	0,556
5	West Windows	A	3,13	m²		West Windows	0,649
6	Horizontal Windows	A	0,00	m²		Horizontal Windows	
7	Exterior Door	A	5,58	m²	*Please subtract area of door from respective building element*	Exterior Door	0,770
8	Exterior Wall - Ambient	A	129,07	m²	*Window areas are subtracted from the individual areas specified in the "Windows" worksheet.*	Exterior Wall - Ambient	0,092
9	Exterior Wall - Ground	B	0,00	m²	*Temperature Zone "A" is ambient air.*	Exterior Wall - Ground	
10	Roof/Ceiling - Ambient	A	57,80	m²	*Temperature zone "B" is the ground.*	Roof/Ceiling - Ambient	0,089
11	Floor slab / basement ceiling	B	51,55	m²		Floor slab / basement ceiling	0,099
12			0,00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"*		
13			0,00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"* Factor for X		
14		X	0,00	m²	*Temperature zone "X": Please provide user-defined reduction factor (0 < f, < 1):* 75%		
						Thermal Bridge Overview	Ψ [W/(mK)]
15	Thermal Bridges Ambient	A	3,60	m	*Units in m*	Thermal Bridges Ambient	0,001
16	Perimeter Thermal Bridges	P	0,00	m	*Units in m; temperature zone "P" is perimeter (see Ground worksheet).*	Perimeter Thermal Bridges	
17	Thermal Bridges Floor Slab	B	0,00	m	*Units in m*	Thermal Bridges Floor Slab	
18	Partition Wall to Neighbour	I	0,00	m²	*No heat losses, only considered for the heating load calculation.*	Partition Wall to Neighbour	
Total thermal envelope			275,07	m²		Average Therm. Envelope	0,162

Area input

Area Nr.	Building element description	Group Nr.	Assigned to group	Quantity	x (	a [m]	x	b [m]	+	User-Determined [m²]	-	User Subtraction [m²]	-	Subtraction window areas [m²]	) =	Area [m²]	Selection of the corresponding building element assembly	Nr.	U-Value [W/(m²K)]
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	106,06	-				) =	106,1			
	North Windows	2	North Windows													3,1	From Windows sheet		0,649
	East Windows	3	East Windows													3,5	From Windows sheet		0,631
	South Windows	4	South Windows	Please complete in Windows worksheet only!												21,3	From Windows sheet		0,558
	West Windows	5	West Windows													3,1	From Windows sheet		0,649
	Horizontal Windows	6	Horizontal Windows													0,0	From Windows sheet		0,000
	Exterior Door	7	Exterior Door	1	x (		x		+	5,58	-		) -		=	5,6	U-Value Exterior Door		0,77
1	Exterior wall south (plaster	8	Exterior Wall - Ambient	1	x (		x		+	18,07	-	1,12	) -	10,7	=	6,3	Exterior wall (plaster	1	0,092
2	Exterior wall north (plaster	8	Exterior Wall - Ambient	1	x (		x		+	24,75	-	1,43	) -	0,0	=	23,3	Exterior wall (plaster	1	0,092
3	Exterior wall west (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	42,14	-	1,34	) -	3,1	=	37,7	Exterior wall (plaster	1	0,092
4	Exterior wall east (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	33,90	-	5,22	) -	0,6	=	28,1	Exterior wall (plaster	1	0,092
5	Exterior wall south (panels)	8	Exterior Wall - Ambient	1	x (		x		+	19,02	-	1,12	) -	10,7	=	7,2	Exterior wall (panels	2	0,091
6	Exterior wall north (panels)	8	Exterior Wall - Ambient	1	x (		x		+	12,33	-	0,94	) -	3,1	=	8,3	Exterior wall (panels	2	0,091
7	Exterior wall west (panels)	8	Exterior Wall - Ambient	1	x (		x		+	3,28	-	3,20	) -	0,0	=	0,1	Exterior wall (panels	2	0,091
8	Exterior wall east (panels)	8	Exterior Wall - Ambient	1	x (		x		+	11,52	-	1,69	) -	2,9	=	6,9	Exterior wall (panels	2	0,091
9					x (		x		+		-		) -	0,0	=			4	
10	Floor slab	11	Floor slab / basement ceiling	1	x (		x		+	51,55	-		) -	0,0	=	51,6	Ground floor	3	0,099
11	Lintels - windows (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	1,60	-		) -	0,0	=	1,6	Lintels (plaster)	6	0,100
12	Lintels - windows (panels)	8	Exterior Wall - Ambient	1	x (		x		+	3,15	-		) -	0,0	=	3,2	Lintels (panels)	7	0,099
13	Lintels - door (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	0,29	-		) -	0,0	=	0,3	Lintels (plaster)	6	0,100
14	Lintels - door (panels)	8	Exterior Wall - Ambient	1	x (		x		+	0,29	-		) -	0,0	=	0,3	Lintels (panels)	7	0,099
15	Roof - joist beam 1	10	Roof/Ceiling - Ambient	1	x (		x		+	1,36	-		) -	0,0	=	1,4	Roof - joist 1	5	0,133
16	Roof - joist beam 2	10	Roof/Ceiling - Ambient	1	x (		x		+	1,36	-		) -	0,0	=	1,4	Roof - joist 2 (murlat	10	0,131
17	Roof - joist beam 3	10	Roof/Ceiling - Ambient	1	x (		x		+	1,36	-		) -	0,0	=	1,4	Roof - joist 3	11	0,129
18	Roof - insulation	10	Roof/Ceiling - Ambient	1	x (		x		+	52,49	-		) -	0,0	=	52,5	Roof - insulation - m	15	0,085
19	Roof - gutter	10	Roof/Ceiling - Ambient	1	x (		x		+	1,23	-		) -	0,0	=	1,2	Roof - gutter (rynna)	14	0,095
20	Wall - spine beam (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	0,66	-		) -	0,0	=	0,7	Wall - Spine beam (	8	0,100
21	Wall - spine beam (panels)	8	Exterior Wall - Ambient	1	x (		x		+	1,19	-		) -	0,0	=	1,2	Wall - Spine beam (	9	0,099
22	Pillar (panels)	8	Exterior Wall - Ambient	1	x (		x		+	1,16	-		) -	0,0	=	1,2	Wall - Pillar (panels)	16	0,099
23	Pillar (plaster)	8	Exterior Wall - Ambient	1	x (		x		+	2,85	-		) -	0,0	=	2,9	Wall - Pillar (plaster)	17	0,100
24					x (		x		+		-		) -	0,0	=			0	

Thermal Bridge Inputs

No.	Thermal bridge description	Group Nr.	Assigned to group	Quantity	x (	User determined length [m]	-	Subtraction user-determined length [m]	)=	Length l [m]	Input of thermal bridge heat loss coefficient W/(mK)	Ψ W/(mK)
1	Windows + door(jamb)	8	Exterior Wall - Ambient	1	x (	89,30	-		) =	89,30	Windows + door(jamb)	0,021
2	Stairs	15	Thermal Bridges Ambient	1	x (	3,60	-		) =	3,60	Stairs	0,001
3	Roof - exterior wall	10	Roof/Ceiling - Ambient	1	x (	30,91	-		) =	30,91	Roof - exterior wall	-0,021
4	Floor slab - exterior wall	11	Floor slab / basement ceiling	1	x (	30,91	-		) =	30,91	Floor slab - exterior wall	-0,092
5	Exterior wall corner	8	Exterior Wall - Ambient	4	x (	5,34	-		) =	21,36	Exterior wall corner	-0,054
6	Spine beam	8	Exterior Wall - Ambient	1	x (	30,91	-		) =	30,91	Spine beam	0,023
7					x (		-		) =			

Annex 1.2.3: “U-List“ Worksheet

Passive House verification

U - LIST

Compilation of the building elements calculated in the U-Values worksheet and other construction types from databases.

	Type		
Assembly No.	Assembly description	Total thickness	U-Value
		m	W/(m²K)
1	Exterior wall (plaster)	0,567	0,092
2	Exterior wall (panels)	0,580	0,091
3	Ground floor	0,520	0,099
4			
5	Roof - joist 1	0,795	0,133
6	Lintels (plaster)	0,567	0,100
7	Lintels (panels)	0,580	0,099
8	Wall - Spine beam (plaster) - wieniec	0,567	0,100
9	Wall - Spine beam (panels) - wieniec	0,580	0,099
10	Roof - joist 2 (murłata)	0,895	0,131
11	Roof - joist 3	0,995	0,129
12			
13			
14	Roof - gutter	0,567	0,095
15	Roof - insulation - medium height	0,885	0,085
16	Wall - Pillar (panels)	0,580	0,099
17	Wall - Pillar (plaster)	0,567	0,100
18			
19			

Annex 1.1.4: "U-Values"

Passive House verification

U-VALUES OF BUILDING ELEMENTS

Building: Passive House

Wedge shaped building element layers and still air spaces -> Secondary calculation to the right

Assembly No. 1 – Building assembly description: Exterior wall (plaster) – Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi: 0,13; exterior Rse: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Airbrick - Porotherm Dr	0,238					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							

Percentage of Sec. 2 – Percentage of Sec. 3 – Total: 56,7 cm

U-Value: 0,092 W/(m²K)

Assembly No. 2 – Building assembly description: Exterior wall (panels) – Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi: 0,13; exterior Rse: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Airbrick - Porotherm Dr	0,238					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2 – Percentage of Sec. 3 – Total: 58,0 cm

U-Value: 0,091 W/(m²K)

Assembly No. 3 – Building assembly description: Ground floor – Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi: 0,17; exterior Rse: 0,00

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Ceramic tiles	1,070					10
2.	Concrete screed	1,300					50
3.	Styrofoam - Termo Organ	0,031					300
4.	Damp insulation	0,180					10
5.	Concrete screed	1,300					50
6.	Compacted rubble	0,770					100
7.							
8.							

Percentage of Sec. 2 – Percentage of Sec. 3 – Total: 52,0 cm

U-Value: 0,099 W/(m²K)

Assembly No. Building assembly description: 4 Roof - joist 1 | Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,10 | exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Precast beam and block	0,649					240
6.	Mineral wool - Isover	0,030					150
7.	Plasterboard	0,230					25
8.							
			Percentage of Sec. 2	10,0%	Percentage of Sec. 3		Total 79,5 cm

U-Value: 0,133 W/(m²K)

Assembly No. Building assembly description: 5 Lintels (plaster) | Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,13 | exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Concrete	1,300	Reinforced concrete	1,700			250
3.	Styrofoam - Termo Organi	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							
			Percentage of Sec. 2	55,0%	Percentage of Sec. 3		Total 56,7 cm

U-Value: 0,100 W/(m²K)

Assembly No. Building assembly description: 6 Lintels (panels) | Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,13 | exterior Rse : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Concrete	1,300	Reinforced concrete	1,700			250
3.	Styrofoam - Termo Organi	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							
			Percentage of Sec. 2	55,0%	Percentage of Sec. 3		Total 58,0 cm

U-Value: 0,099 W/(m²K)

Assembly No. 7 — Building assembly description: Wall - Spine beam (plaster) - wieniec

Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,13; exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organi	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							

Percentage of Sec. 2: — Percentage of Sec. 3: — Total: 56,7 cm

U-Value: 0,100 W/(m²K)

Assembly No. 8 — Building assembly description: Wall - Spine beam (panels) - wieniec

Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,13; exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organi	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2: — Percentage of Sec. 3: — Total: 58,0 cm

U-Value: 0,099 W/(m²K)

Assembly No. 9 — Building assembly description: Roof - joist 2 (murłata)

Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,10; exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Brick wall	0,770					100
6.	Precast beam and block	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25

Percentage of Sec. 2: 9,0% — Percentage of Sec. 3: — Total: 89,5 cm

U-Value: 0,131 W/(m²K)

Assembly No.	Building assembly description		Interior insulation?
10	Roof - joist 3		

Heat transfer resistance [m²K/W] interior Rsi : 0,10 exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Joist beam	0,160					160
5.	Brick wall	0,770					200
6.	Precast beam and block	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
			Percentage of Sec. 2	9,0%	Percentage of Sec. 3		Total 99,5 cm

U-Value: 0,129 W/(m²K)

Assembly No.	Building assembly description		Interior insulation?
11	Roof - gutter		

Heat transfer resistance [m²K/W] interior Rsi : 0,10 exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roof membrane	0,040					2
2.	Styrofoam - Termo Organi	0,031					150
3.	Precast beam and block	0,649					240
4.	Mineral wool - Isover	0,030					150
5.	Plasterboard	0,230					25
6.							
7.							
8.							
			Percentage of Sec. 2		Percentage of Sec. 3		Total 56,7 cm

U-Value: 0,095 W/(m²K)

Assembly No.	Building assembly description		Interior insulation?
12	Roof - insulation - medium height		

Heat transfer resistance [m²K/W] interior Rsi : 0,10 exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Roofing felt	0,700					20
2.	Full boarding	0,160					40
3.	Hollow core	0,270	Rafter	0,160			160
4.	Hollow core	0,270					100
5.	Styrofoam - Termo Organi	0,031					150
6.	Precast beam and block	0,649					240
7.	Mineral wool - Isover	0,030					150
8.	Plasterboard	0,230					25
			Percentage of Sec. 2	9,0%	Percentage of Sec. 3		Total 88,5 cm

U-Value: 0,085 W/(m²K)

Assembly No.	Building assembly description					Interior insulation?
13	Wall - Pillar (panels)					

Heat transfer resistance [m²K/W] interior R_{si}: 0,13; exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Wooden facade panels	0,130					15
5.							
6.							
7.							
8.							
			Percentage of Sec. 2		Percentage of Sec. 3		Total 58,0 cm

U-Value: 0,099 W/(m²K)

Assembly No.	Building assembly description					Interior insulation?
14	Wall - Pillar (plaster)					

Heat transfer resistance [m²K/W] interior R_{si}: 0,13; exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior lime plaster	0,700					15
2.	Reinforced concrete	1,700					250
3.	Styrofoam - Termo Organ	0,031					300
4.	Silicate plaster	0,800					2
5.							
6.							
7.							
8.							
			Percentage of Sec. 2		Percentage of Sec. 3		Total 56,7 cm

U-Value: 0,100 W/(m²K)

Annex 1.2.5: “Ground“ Worksheet

Passive House verification

HEAT LOSSES VIA THE GROUND

Ground Characteristics			
Thermal Conductivity	λ	2,0	W/(mK)
Heat Capacity	ρc	2,0	MJ/(m³K)
Periodic Penetration Depth	δ	3,17	m

Climate Data			
Av. Indoor Temp. Winter	T_i	20,0	°C
Av. Indoor Temp. Summer	T_i	25,0	°C
Average Ground Surface Temperature	$T_{g,ave}$	9,3	°C
Amplitude of $T_{g,ave}$	$T_{g,^}$	10,0	°C
Length of the Heating Period	n	7,2	months
Heating Degree Hours - Exterior	G_t	89,3	kKh/a

Building Data			
Floor Slab Area	A	69,0	m²
Floor Slab Perimeter	P	34,4	m
Charact. Dimension of Floor Slab	B'	4,01	m

U-value floor slab/basement ceiling	U_f	0,099	W/(m²K)
Thermal bridges floor slab/basement cei	Ψ_B*l	0,00	W/K
U-value floor slab/basement ceiling incl.	U_f'	0,099	W/(m²K)
Eq. Thickness Floor	d_t	20,20	m

Floor Slab Type (select only one)

	Heated Basement or Underground Floor Slab		Unheated basement
x	Slab on Grade		Suspended Floor

For Basement or Underground Floor Slab			
Basement Depth	z		m
U-Value Belowground Wall	U_{wB}		W/(m²K)
Additionally for Unheated Basements			
Air Change Unheated Basement	n		h⁻¹
Basement Volume	V		m³
Height Aboveground Wall	h		m
U-Value Aboveground Wall	U_W	0,092	W/(m²K)
U-Value Basement Floor Slab	U_{fB}		W/(m²K)

For Perimeter Insulation for Slab on Grade			
Perimeter Insulation Width/Depth	D	1,00	m
Perimeter Insulation Thickness	d_n	0,12	m
Conductivity Perimeter Insulation	λ_n	0,031	W/(mK)
Orientation of the Perimeter Ins.	horizontal		
(check only one field)	vertical	x	

For Suspended Floor			
U-Value Crawl Space	U_{Crawl}		W/(m²K)
Height of Crawl Space Wall	h		m
U-Value Crawl Space Wall	U_W		W/(m²K)
Area of Ventilation Openings	εP		m²
Wind Velocity at 10 m Height	v	4,0	m/s
Wind Shield factor	f_W	0,05	-

Additional Thermal Bridge Heat Losses at Perimeter			
Phase Shift	β		months
Steady-State Fraction	$\Psi_{P,stat}$*l	0,000	W/K
Harmonic Fraction	$\Psi_{P,harm}$*l	0,000	W/K

Groundwater Correction			
Depth of the Groundwater Table	z_w	3,0	m
Groundwater Flow Rate	q_w	0,05	m/d
Groundwater Correction Factor	G_w	1,000868	-
Transm. Belowground El. (w/o Ground)	L_{eq}	6,83	W/K
Relative Insulation Standard	d_t/B'	5,04	-
Relative Groundwater Depth	z_w/B'	0,75	-
Relative Groundwater Velocity	l/B'	0,21	-

Basement or Underground Floor Slab			
Eq. Thickness Floor Slab	d_t		m
U-Value Floor Slab	U_{bf}		W/(m²K)
Eq. Thickness Basement Wall	d_w		m
U-Value Wall	U_{bw}		W/(m²K)
Steady-State Transmittance	L_s		W/K
Phase Shift	β		months
Exterior Periodic Transmittance	L_{pe}		W/K

Unheated Basement			
Steady-State Transmittance	L_s		W/K
Phase Shift	β		months
Exterior Periodic Transmittance	L_{pe}		W/K

Slab on Grade			
Heat Transfer Coefficient	U_0	0,09	W/(m²K)
Eq. Ins. Thickness Perimeter Ins.	d'	7,62	m
Perimeter Insulation Correction	$\Delta\Psi$	-0,02	W/(mK)
Steady-State Transmittance	L_s	5,72	W/K
Phase Shift	β	1,44	months
Exterior Periodic Transmittance	L_{pe}	3,26	W/K

Suspended Floor Above a Ventilated Crawl Space (at max. 0.5 m Below Ground)			
Eq. Ins. Thickness Crawl Space	d_g		m
U-Value Crawl Space Floor Slab	U_g		W/(m²K)
U-Value Crawl Space Wall & Vent.	U_x		W/(m²K)
Steady-State Transmittance	L_s		W/K
Phase Shift	β		months
Exterior Periodic Transmittance	L_{pe}		W/K

Interim Results			
Phase Shift	β	1,44	months
Steady-State Transmittance	L_s	5,72	W/K
Exterior Periodic Transmittance	L_{pe}	3,26	W/K
Steady-State Heat Flow	Φ_{stat}	64,0	W
Periodic Heat Flow	Φ_{harm}	11,4	W
Heat Losses During Heating Period	Q_{tot}	395	kWh

Ground reduction factor for "Annual Heating Demand" sheet **0,65**

Monthly Average Ground Temperatures for Monthly Method

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average Value
Winter	7,8	6,7	6,8	8,0	10,0	12,4	14,4	15,5	15,4	14,2	12,1	9,8	11,1
Summer	8,5	7,4	7,5	8,7	10,8	13,1	15,1	16,2	16,1	14,9	12,8	10,5	11,8

Design Ground Temperature for Heating Load Sheet 6,7 **for Cooling Load Sheet** 16,2

Annex 1.2.6: “Windows“ Worksheet

					Window rough openings		Installed		Glazing		Frame		g-Value	U-Value		Ψ-Spacer
Quan-tity	Description	Deviation from north	Angle of inclination from the horizontal	Orientation	Width	Height	in Area in the Areas worksheet	Nr.	Select glazing from the WinType worksheet	Nr.	Select window from the WinType worksheet	Nr.	Perpen-dicular Radiation	Glazing	Frames (centre)	Ψ_{spacer} (centre)
		Degrees	Degrees		m	m	Select:		Select:		Select:		-	W/(m²K)	W/(m²K)	W/(mK)
1	South	180	90	South	2,000	1,450	Exterior	1	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	South	180	90	South	3,300	2,350	Exterior	1	Custom	1	Custom	1	0,50	0,49	0,66	0,021
2	North	0	90	North	1,400	0,600	Exterior	6	Custom	1	Custom	1	0,50	0,49	0,67	0,021
1	North	0	90	North	1,000	1,450	Exterior	6	Custom	1	Custom	1	0,50	0,49	0,66	0,021
2	East	90	90	East	1,000	1,450	Exterior	8	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	East	90	90	East	1,000	0,600	Exterior	4	Custom	1	Custom	1	0,50	0,49	0,67	0,021
2	West	270	90	West	1,400	0,600	Exterior	3	Custom	1	Custom	1	0,50	0,49	0,67	0,021
1	West	270	90	West	1,000	1,450	Exterior	3	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	South	180	90	South	2,000	1,450	Exterior	5	Custom	1	Custom	1	0,50	0,49	0,66	0,021
1	South	180	90	South	3,300	2,350	Exterior	5	Custom	1	Custom	1	0,50	0,49	0,66	0,021

Installation									Results (unhide cells to make U- & Ψ-values from WinType worksheet visible)				Frame-U-values from WinTpye worksheet			
Left 1/0	Right 1/0	Bottom 1/0	Top 1/0	$\Psi_{installation}$ left	$\Psi_{installation}$ right	$\Psi_{installation}$ bottom	$\Psi_{installation}$ top	$\Psi_{installation}$ Average value	Window Area	Glazing Area	U-Value Window	Glazed Fraction per Window	Frame left	Frame right	Frame bottom	Frame top
				W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	m²	m²	W/(m²K)	%	W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)
1	1	1	1					0,010	2,9	2,51	0,58	87%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	7,8	7,11	0,55	92%	0,64	0,64	0,72	0,64
1	1	1	1					0,011	1,7	1,24	0,68	74%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	1,5	1,18	0,62	81%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	2,9	2,36	0,62	81%	0,64	0,64	0,72	0,64
1	1	1	1					0,011	0,6	0,43	0,69	71%	0,64	0,64	0,72	0,64
1	1	1	1					0,011	1,7	1,24	0,68	74%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	1,5	1,18	0,62	81%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	2,9	2,51	0,58	87%	0,64	0,64	0,72	0,64
1	1	1	1					0,010	7,8	7,11	0,55	92%	0,64	0,64	0,72	0,64

Frame measures from WinType worksheet

Width - Left	Width - Right	Width - Below	Width - Above	Area left	Area right	Area bottom	Area top	Total area	Glazing edge length left	Glazing edge length right	Glazing edge length bottom	Glazing edge length top	Total glazing edge length	Installation length left	Installation length right	Installation length bottom	Installation length top	Total installation length
m	m	m	m	m²	m²	m²	m²	m²	m	m	m	m	m	m	m	m	m	m
0,06	0,06	0,06	0,06	0,08	0,08	0,12	0,12	0,39	1,33	1,33	1,88	1,88	6,44	1,45	1,45	2,00	2,00	6,90
0,06	0,06	0,06	0,06	0,13	0,13	0,19	0,19	0,64	2,23	2,23	3,18	3,18	10,84	2,35	2,35	3,30	3,30	11,30
0,06	0,06	0,06	0,06	0,03	0,03	0,08	0,08	0,22	0,48	0,48	1,28	1,28	3,54	0,60	0,60	1,40	1,40	4,00
0,06	0,06	0,06	0,06	0,08	0,08	0,06	0,06	0,27	1,33	1,33	0,88	0,88	4,44	1,45	1,45	1,00	1,00	4,90
0,06	0,06	0,06	0,06	0,08	0,08	0,06	0,06	0,27	1,33	1,33	0,88	0,88	4,44	1,45	1,45	1,00	1,00	4,90
0,06	0,06	0,06	0,06	0,03	0,03	0,06	0,06	0,17	0,48	0,48	0,88	0,88	2,74	0,60	0,60	1,00	1,00	3,20
0,06	0,06	0,06	0,06	0,03	0,03	0,08	0,08	0,22	0,48	0,48	1,28	1,28	3,54	0,60	0,60	1,40	1,40	4,00
0,06	0,06	0,06	0,06	0,08	0,08	0,06	0,06	0,27	1,33	1,33	0,88	0,88	4,44	1,45	1,45	1,00	1,00	4,90
0,06	0,06	0,06	0,06	0,08	0,08	0,12	0,12	0,39	1,33	1,33	1,88	1,88	6,44	1,45	1,45	2,00	2,00	6,90
0,06	0,06	0,06	0,06	0,13	0,13	0,19	0,19	0,64	2,23	2,23	3,18	3,18	10,84	2,35	2,35	3,30	3,30	11,30

	Thermal bridges									Installation length	
n	$\Psi_{glazing\ edge}$ left	$\Psi_{glazing\ edge}$ right	$\Psi_{glazing\ edge}$ bottom	$\Psi_{glazing\ edge}$ top	$\Psi_{installation}$ left	$\Psi_{installation}$ right	$\Psi_{installation}$ bottom	$\Psi_{installation}$ top	Descrip-tion	Glazing	Frames
	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)		m	m
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	6,4	6,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	10,8	11,3
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	North	7,1	8,0
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	North	4,4	4,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	East	8,9	9,8
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	East	2,7	3,2
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	West	7,1	8,0
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	West	4,4	4,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	6,4	6,9
	0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	South	10,8	11,3

Annex 1.2.7: “WinType“ Worksheet

Passive House verification

GLAZING ACCORDING TO CERTIFICATION

Go to curtain wall facades / window frames from line 99 onwards

	Type		
Assem-bly No.	Glazing	g-Value	U_g-Value
			W/(m²K)
1	Custom glazing	0,50	0,49
2			

CURTAIN WALL FACADE / WINDOW FRAME AS PER CERTIFICATE

Go to glazing from line 2 onwards

	Type	U_f-Value				Frame Dimensions			
Assem-bly No.	Window frame	Frame left	Frame right	Frame bottom	Frame top	Width - Left	Width - Right	Width - Below	Width - Above
	Curtain wall facade	Post left	Post right	Beam bottom	Beam top	Post left	Post right	Beam bottom	Beam top
		W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)	m	m	m	m
1	Custom frame	0,64	0,64	0,72	0,64	0,058	0,058	0,058	0,058
2									

Thermal bridges								
Glazing edge thermal bridge				Installation thermal bridge				Curtain wall facades:
$\Psi_{Glazing\ edge}$ left	$\Psi_{Glazing\ edge}$ right	$\Psi_{Glazing\ edge}$ bottom	$\Psi_{Glazing\ edge}$ top	$\Psi_{Installation}$ left	$\Psi_{Installation}$ right	$\Psi_{Installation}$ bottom	$\Psi_{Installation}$ top	χ_{GC} -value Glass carrier
W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/K
0,021	0,021	0,021	0,021	0,008	0,008	0,016	0,008	

Annex 1.2.8: “Shading“ Worksheet

Passive House verification

CALCULATING SHADING FACTORS

Climate: PL - Strefa II (Poznan/Pila)
Building: Passive House
Latitude: 52,42 °

Orientation	Glazing area m^2	Reduction factor r_S
North	2,42	78%
East	2,79	77%
South	19,25	79%
West	2,42	77%
Horizontal	0,00	100%

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing width	Glazing height	Glazing area	Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional shading reduction factor	Horizontal shading reduction factor	Reveal Shading Reduction Factor	Overhang shading reduction factor	Total shading reduction factor
		Degrees	Degrees		m	m		m	m	m	m	m	m	%	%	%	%	%
					w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}	r_H	r_R	r_O	r_S
1	South	180	90	South	1,88	1,33	2,5	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	99%	100%	79%
1	South	180	90	South	3,18	2,23	7,1	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	99%	100%	80%
2	North	0	90	North	1,28	0,48	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	98%	100%	78%
1	North	0	90	North	0,88	1,33	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	97%	100%	78%
2	East	90	90	East	0,88	1,33	2,4	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	96%	100%	77%
1	East	90	90	East	0,88	0,48	0,4	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	96%	100%	77%
2	West	270	90	West	1,28	0,48	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	97%	100%	78%
1	West	270	90	West	0,88	1,33	1,2	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	96%	100%	77%
1	South	180	90	South	1,88	1,33	2,5	0,00	0,00	0,05	0,080	0,00	0,00	80%	100%	99%	100%	79%
1	South	180	90	South	3,18	2,23	7,1	0,00	0,00	0,05	[illegible]	0,00	0,00	80%	100%	99%	100%	80%

Annex 1.2.9: “Ventilation“ Wroksheet

Passive House verification

VENTILATION DATA

Building: Passive House

Treated floor area A_{TFA}		m²	106	(Areas worksheet)
Room height h		m	2,5	(Annual Heating Demand worksheet)
Room ventilation volume (A_{TFA}*h) =	V_V	m³	265	(Annual Heating Demand worksheet)

Type of ventilation system

	Balanced PH ventilation	Please Check
x	Pure extract air	

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for screening class	Several sides exposed	One side exposed
No screening	0,10	0,03
Moderate screening	0,07	0,02
High screening	0,04	0,01
Coefficient f	15	20

			for Annual Demand:	for Heating Load:				
Wind protection coefficient, e			0,07	0,18				
Wind protection coefficient, f			15	15	Net Air Volume for Press. Test V_{n50}		Air permeability q_{50}	
Air Change Rate at Press. Test	n_{50}	1/h	0,60	0,60	531	m³	1,16	m³/(hm²)

			for Annual Demand:	for Heating Load:
Excess extract air		1/h	0,41	0,41
Infiltration air change rate	$n_{V,Res}$	1/h	0,001	0,005

Selection of ventilation data input - Results

The PHPP offers two methods for dimensioning the air quantities and choosing the ventilation unit. Fresh air or extract air quantities for residential buildings and parameters for ventilation systems with a maximum of 1 ventilation unit can be determined using the standard planning option in the 'Ventilation' sheet. The 'Additional Vent' sheet has been created for more complex ventilation systems and allows up to 10 different ventilation units to be taken into account. Furthermore, air quantities can be determined on a room-by-room or zone-by-zone basis. Please select your design method here.

	Ventilation unit / Heat recovery efficiency design		Mean Air exchange m³/h	Mean Air Change Rate 1/h	Extract air excess (Extract air system) 1/h	Effective heat recovery efficiency Unit [-]	Specific power input Wh/m³	Heat recovery efficiency SHX
x	Sheet Ventilation (Standard design)	(Sheet Ventilation see below)	108	0,41	0,41	0,0%	n.s.	0,0%
	Sheet Extended ventilation	(Sheet Additional Vent)						
	(Multiple ventilation units, non-residential buildings)							

SHX efficiency η^*_{SHX} 0%

STANDARD INPUT FOR BALANCED VENTILATION

Ventilation dimensioning for systems with one ventilation unit

	Unit					
Occupancy	m²/P	27				
Number of occupants	P	4,0				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	120				
Extract air rooms		Kitchen	Bathroom	Bathroom (shower only)	WC	Other
Quantity		1	1		1	3
Extract air requirement per room	m³/h	50	30	20	30	10
Total Extract Air Requirement	m³/h	140				

Design air flow rate (maximum) m³/h 140

Average air change rate calculation

Type of operation	Daily operation duration h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
Maximum		1,00	140	0,53
Standard	24,0	0,77	108	0,41
Basic		0,54	75	0,28
Minimum		0,40	56	0,21
	Average value	**0,77**	Average air flow rate (m³/h) **108**	Average air change rate (1/h) **0,41**

Selection of ventilation unit with heat recovery

Central unit within the thermal envelope.

Central unit outside of the thermal envelope.

No heat recovery. Please enter electrical efficiency data.

Please check at least one box

	Heat recovery efficiency Unit η_{HR}	Specific power input [Wh/m³]	Application range [m³/h]	Frost protection required	Unit noise level < 35dB(A)
Ventilation unit selection	n.s.	n.s.	n.s.	n.s.	n.s.

Ψ	W/(mK)	0,000	See calculation below
	m		
Ψ	W/(mK)	0,000	See calculation below
	m		
Temperature of mechanical services room (Enter only if the central unit is outside of the thermal envelope.)	°C		

Room Temperature (°C)	20
Av. Ambient Temp. Heating P. (°C)	3,5
Av. Ground Temp (°C)	9,3

Effective heat recovery efficiency $\eta_{HR,eff}$

Effective heat recovery efficiency subsoil heat exchanger

SHX efficiency	η^*_{SHX}	
Heat recovery efficiency SHX	η_{SHX}	0 %

Secondary calculation

Ψ-value supply or ambient air duct

Nominal width:		mm
Insul. Thickness:		mm
Reflective? Please mark with an "x"!		
Yes	Please check one box only	
No		
Thermal conductivity		W/(mK)
Nominal air flow rate	108	m³/h
Δϑ	17	K
Exterior duct diameter	0,000	m
Exterior diameter	0,000	m
α-Interior	0,00	W/(m²K)
α-Surface		W/(m²K)
Ψ-value		**W/(mK)**
Surface temperature difference		K

Secondary calculation

Ψ-value extract or exhaust air duct

Nominal width:		mm
Insul. Thickness:		mm
Reflective? Please mark with an "x"!		
Yes	Please check one box only	
No		
Thermal conductivity		W/(mK)
Nominal air flow rate	108	m³/h
Δϑ	17	K
Exterior duct diameter	0,000	m
Exterior diameter	0,000	m
α-Interior	0,00	W/(m²K)
α-Surface		W/(m²K)
Ψ-value		**W/(mK)**
Surface temperature difference		K

Annex 1.2.10: “Annual Heating Demand“ Worksheet

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND

Climate:	PL - Strefa II (Poznan/Pila)	Interior Temperature:	20,4 °C
Building:	Passive House	Building Type/Use:	Dwelling
		Treated Floor Area A_{TFA}:	106,1 m²

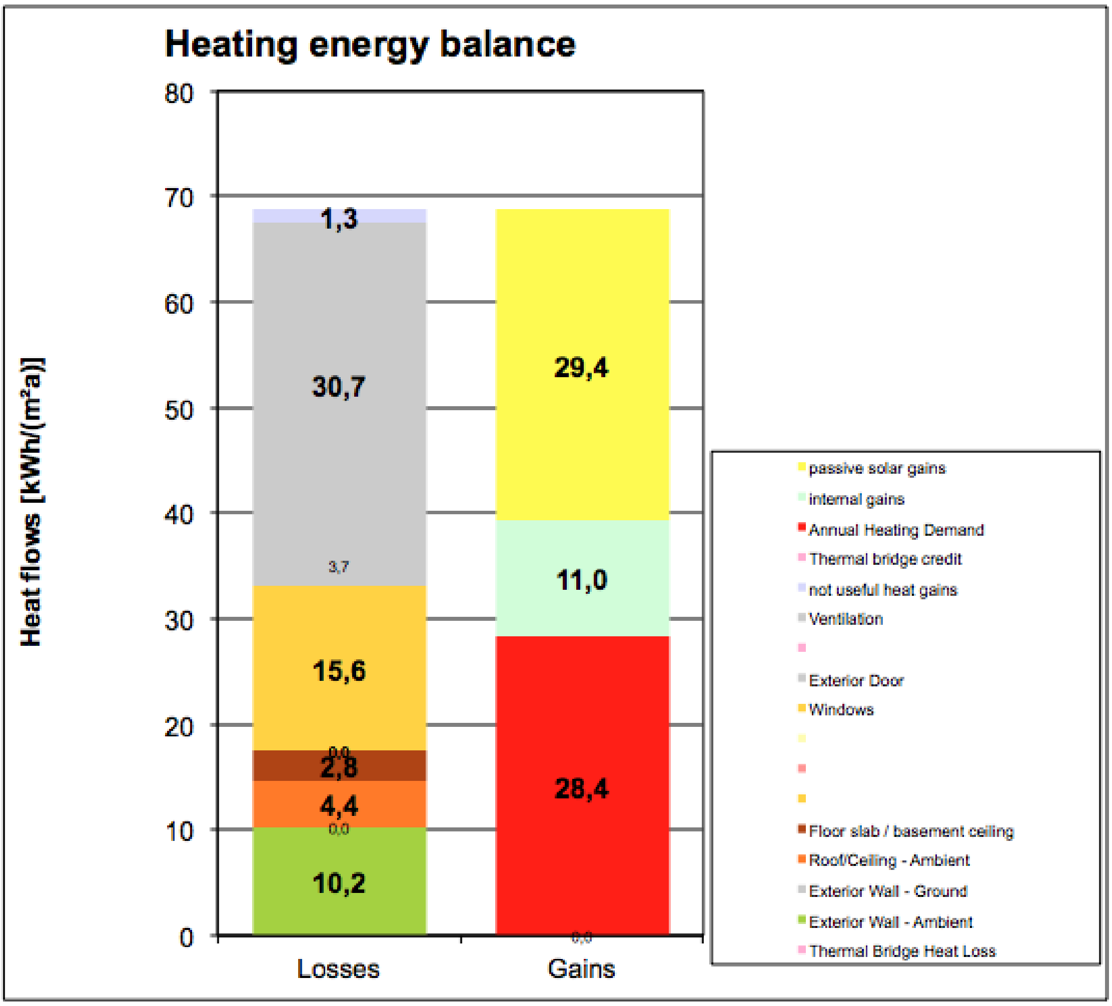
Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Temp. Factor f_t		G_t kKh/a		kWh/a	per m² Treated Floor Area
Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	*	91,3	=	1084	10,22
Exterior Wall - Ground	B		*		*	0,65	*		=		
Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	*	91,3	=	468	4,41
Floor slab / basement ceiling	B	51,6	*	0,099	*	0,65	*	91,3	=	302	2,85
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Windows	A	31,1	*	0,585	*	1,00	*	91,3	=	1659	15,64
Exterior Door	A	5,6	*	0,770	*	1,00	*	91,3	=	392	3,70
Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	*	91,3	=	0	0,00
Perimeter TB (length/m)	P		*		*	0,65	*		=		0,00
Ground TB (length/m)	B		*		*	0,65	*		=		
Total of All Building Envelope Areas		275,1									kWh/(m²a)
Transmission Heat Losses Q_T									Total	3906	36,8

			A_{TFA} m²		Clear Room Height m		m³	
Ventilation System:	Effective Air Volume, V_V		106,1	*	2,50	=	265,2	
Effective Heat Recovery Efficiency η_{eff}	0%							
of Heat Recovery								
Efficiency of Subsoil Heat Exchanger η_{SHX}	0%							
		$n_{V,system}$ 1/h	Φ_{HR}		$n_{V,Res}$ 1/h		1/h	
Energetically Effective Air Exchange n_V		0,407	* (1 - 0,00) +		0,001	=	0,407	
	V_V m³	n_V 1/h	c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	265	* 0,407	* 0,33	*	91,3	=	3253	30,7
		Q_T kWh/a	Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L		(3906	+ 3253	)	1,0	=	7159	67,5

Total Heat Losses Q_L (3906 + 3253) 1,0 = 7159 67,5

Orientation of the Area	Reduction Factor See Windows Sheet		g-Value (perp. radiation)		Area m²		Radiation HP kWh/(m²a)		kWh/a
1. North	0,49	*	0,50	*	3,13	*	237	=	181
2. East	0,49	*	0,50	*	3,50	*	293	=	253
3. South	0,58	*	0,50	*	21,31	*	401	=	2478
4. West	0,48	*	0,50	*	3,13	*	278	=	210
5. Horizontal	0,00	*	0,00	*	0,00	*	344	=	0

								kWh/(m²a)
Available Solar Heat Gains Q_S						Total	3121	29,4
	kh/d	Length Heat. Period d/a	Spec. Power q_i W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	* 218	* 2,10	*	106,1	=	1167	11,0
							kWh/a	kWh/(m²a)
		Free Heat Q_F			Q_S + Q_I	=	4288	40,4
		Ratio of Free Heat to Losses			Q_F / Q_L	=	0,60	
Utilisation Factor Heat Gains η_G			$(1 - (Q_F/Q_L)^5) / (1 - (Q_F/Q_L)^6)$			=	97%	
							kWh/a	kWh/(m²a)
Heat Gains Q_G					η_G * Q_F	=	4149	39,1
							kWh/a	kWh/(m²a)
Annual Heating Demand QH					Q_L - Q_G	=	3010	28
		kWh/(m²a)					(Yes/No)	
	Limiting Value	15			**Requirement met?**		no	


Heating energy balance
Heat flows [kWh/(m²a)]
80
70
60
50
40
30
20
10
0
1,3
30,7
3,7
15,6
0,0
2,8
4,4
0,0
10,2
29,4
11,0
28,4
0,0
Losses
Gains
passive solar gains
internal gains
Annual Heating Demand
Thermal bridge credit
not useful heat gains
Ventilation
Exterior Door
Windows
Floor slab / basement ceiling
Roof/Ceiling - Ambient
Exterior Wall - Ground
Exterior Wall - Ambient
Thermal Bridge Heat Loss

Annex 1.2.11: “Monthly Method“ Worksheet

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND MONTHLY METHOD

(This page displays the sums of the monthly method over the heating period)

Climate:	PL - Strefa II (Poznan/Piła)	Interior Temperature:	20,441 °C
Building:	Passive House	Building Type/Use:	Dwelling
Spec. Capacity:	132 Wh/(m²K) (Enter in "Summer" worksheet.)	Treated Floor Area A_{TFA}:	106,1 m²

Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Month. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area kWh/(m²a)
Exterior Wall - Ambient	A	129,1	*	0,092	*	1,00	*	95	=	1133	
Exterior Wall - Ground	B		*		*	1,00	*		=		
Roof/Ceiling - Ambient	A	57,8	*	0,089	*	1,00	*	95	=	489	
Floor slab / basement ceiling	B	51,6	*	0,099	*	1,00	*	60	=	306	
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Windows	A	31,1	*	0,585	*	1,00	*	95	=	1733	
Exterior Door	A	5,6	*	0,770	*	1,00	*	95	=	410	
Exterior TB (length/m)	A	3,6	*	0,001	*	1,00	*	95	=	0	
Perimeter TB (length/m)	P		*		*	1,00	*		=		
Ground TB (length/m)	B		*		*	1,00	*		=		
Transmission Heat Losses Q_T									Total	4071	38,4

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume V_{RAX}	106	*	2,50	=	265

	$n_{V,system}$ 1/h		η^*_{SHX}		η_{SHR}		$n_{V,Res}$ 1/h		$n_{V,equi\ fraction}$ 1/h
Effective Air Change Rate Ambient $n_{V,e}$	0,407	*(1-	0%	)*(1-	0,00	)+	0,001	=	0,407
Effective Air Change Rate Ground $n_{V,g}$	0,407	*	0%	*(1-	0,00	)		=	0,000

	V_{RAX} m³		$n_{V,equi\ fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Losses Ambient Q_V	265	*	0,407	*	0,33	*	95	=	3399	32,0
Ventilation Losses Ground $Q_{V,e}$	265	*	0,000	*	0,33	*	65	=	0	0,0
Ventilation Heat Losses Q_V								Total	3399	32,0

			Q_T (kWh/a)		Q_V (kWh/a)		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L		(	4071	+	3399	) *	1,0	=	7469	70,4

Orientation of the Area	Reduction Factor See Windows worksheet		g-Value (perp. radiation)		Area (m²)		Global Radiation (kWh/(m²a))		kWh/a	kWh/(m²a)
North	0,49	*	0,50	*	3,1	*	286	=	218	
East	0,49	*	0,50	*	3,5	*	344	=	297	
South	0,58	*	0,50	*	21,3	*	467	=	2885	
West	0,48	*	0,50	*	3,1	*	332	=	251	
Horizontal	0,00	*	0,00	*	0,0	*	401	=	0	
Sum Opaque Areas									51	
Available Solar Heat Gains Q_S								Total	3701	34,9

	kh/d		Length Heat Period (d/a)		Spec. Power q_I (W/m²)		A_{TFA} (m²)		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	242	*	2,1	*	106,1	=	1294	12,2

				kWh/a	kWh/(m²a)
	Free Heat Q_F	Q_S + Q_I	=	4995	47,1
	Ratio Free Heat to Losses	Q_F / Q_L	=	0,67	
Utilisation Factor Heat Gains η_G			=	88%	
Heat Gains Q_G		η_G * Q_F	=	4385	41,3
Annual Heating Demand QH		Q_L - Q_G	=	3085	29

	kWh/(m²a)		(Yes/No)
Limiting Value	15	**Requirement met?**	no

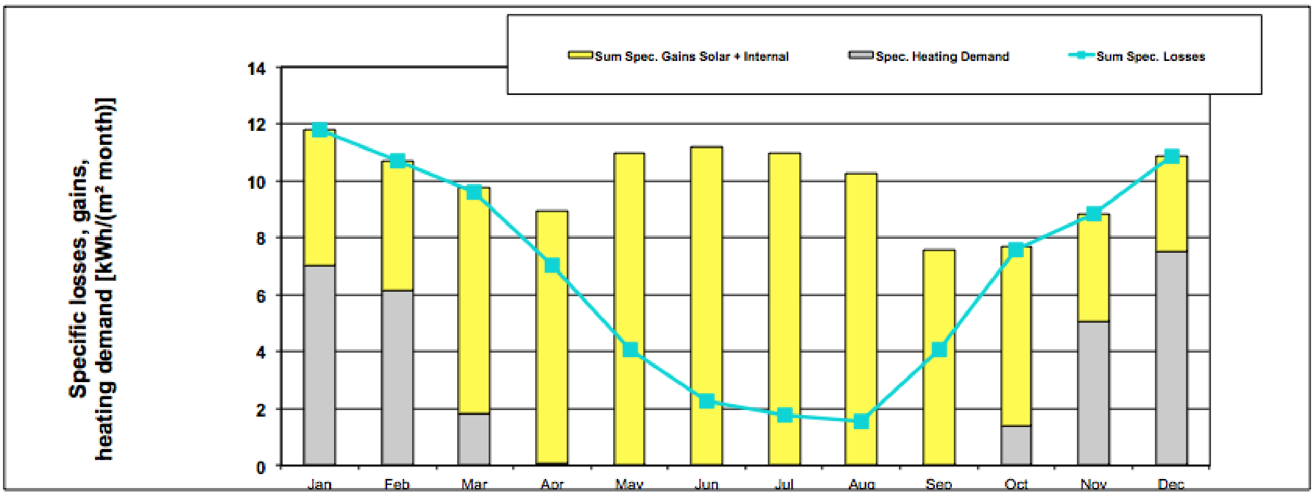
Passive House verification

SPECIFIC ANNUAL HEAT DEMAND MONTHLY METHOD

Climate: PL - Strefa II (Poznan/Pila)
Building: Passive House

Interior Temperature: 20,441 °C
Building Type/Use: Dwelling
Treated Floor Area A_{TFA}: 106 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - Ext	16,0	14,5	12,8	9,3	5,2	2,8	2,3	2,0	5,5	10,4	12,0	14,8	108	kKh
Heating Degree Hours - Gro	9,4	9,2	10,2	9,0	7,7	5,3	4,0	3,2	3,6	4,7	6,0	7,9	80	kKh
Losses - Exterior	1205	1088	965	700	394	213	169	147	413	780	905	1109	8086	kWh
Losses - Ground	48	47	52	46	39	27	20	16	19	24	31	40	409	kWh
Sum Spec. Losses	11,8	10,7	9,6	7,0	4,1	2,3	1,8	1,5	4,1	7,6	8,8	10,8	80,1	kWh/m²
Solar Gains - North	15	16	36	54	66	79	75	64	44	27	14	12	502	kWh
Solar Gains - East	20	23	55	76	104	111	108	89	56	36	18	14	708	kWh
Solar Gains - South	288	269	534	577	731	728	713	679	485	401	187	143	5735	kWh
Solar Gains - West	17	19	43	62	83	91	86	75	50	33	15	12	586	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	4	4	9	12	16	18	17	15	10	7	3	3	117	kWh
Internal Heat Gains	166	150	166	160	166	160	166	166	160	166	160	166	1951	kWh
Sum Spec. Gains Solar + In	4,8	4,5	7,9	8,9	11,0	11,2	11,0	10,2	7,6	6,3	3,8	3,3	90,5	kWh/m²
Utilisation Factor	100%	100%	98%	78%	37%	20%	16%	15%	54%	98%	100%	100%	56%	
Annual Heating Demand	745	654	191	10	0	0	0	0	0	148	537	799	3085	kWh
Spec. Heating Demand	**7,0**	**6,2**	**1,8**	**0,1**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**1,4**	**5,1**	**7,5**	**29,1**	kWh/m²



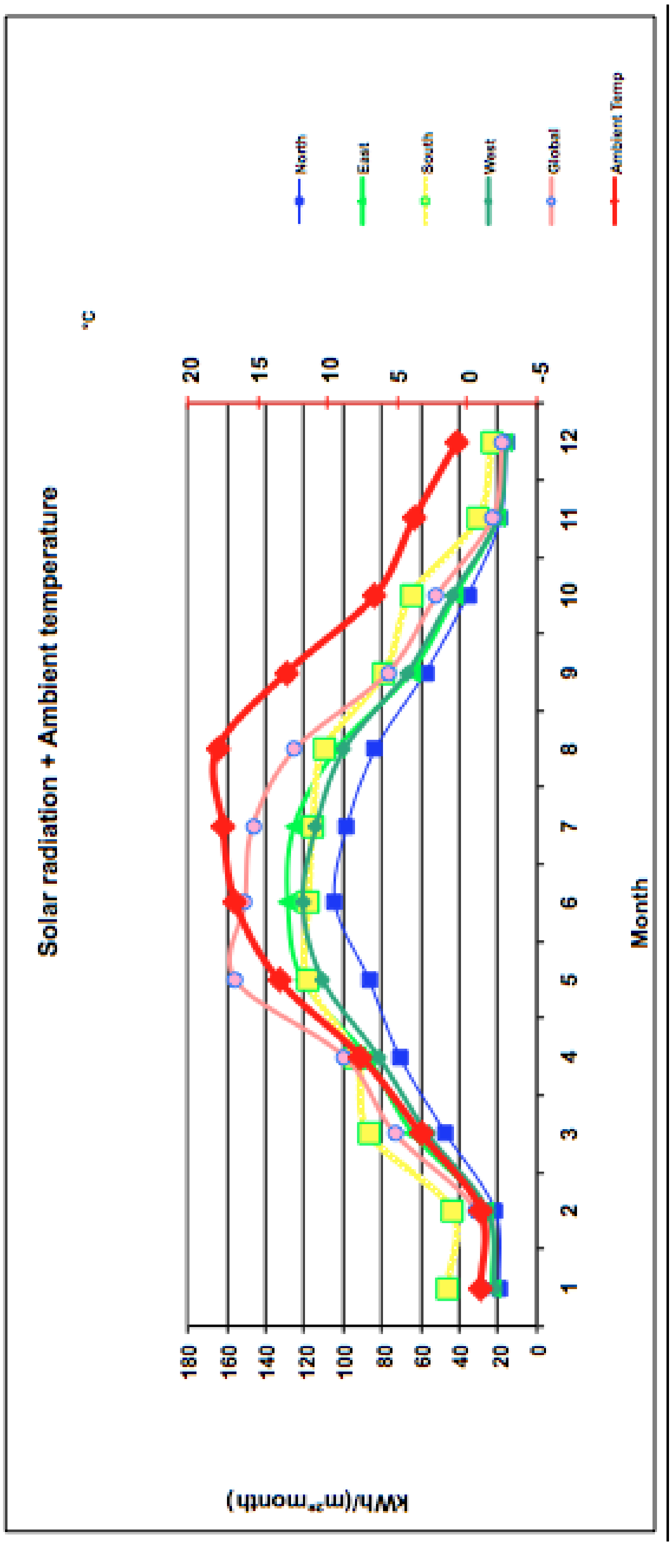
Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total	Heating Period Method
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	218
Ambient Temp.	-1,00	-1,00	3,30	7,60	13,50	16,60	17,50	17,90	12,90	6,60	3,80	0,70	8,3	3,0
North Radiation	19,4	21,5	46,9	70,7	86,5	104,2	97,9	83,3	57,4	35,7	18,7	15,7	658	237
East Radiation	22,6	26,2	63,8	87,7	120,8	128,5	125,2	103,2	64,9	42,2	20,4	16,4	822	293
South Radiation	46,6	43,6	86,5	93,5	118,3	118,0	115,5	109,9	78,6	65,0	30,3	23,2	929	401
West Radiation	22,0	25,5	56,4	81,6	110,5	120,7	113,8	99,3	66,7	43,7	20,5	16,0	777	278
Hori. Radiation	28,0	31,5	73,1	99,3	155,5	150,7	146,6	124,8	76,7	51,6	23,0	17,8	978	344
Tsky	-11,10	-10,30	-7,10	-1,60	4,70	8,50	9,60	10,20	5,20	-2,80	-3,80	-7,60	-0,5	
Ground Temp	7,78	6,68	6,76	7,99	10,05	13,12	15,10	16,20	15,39	14,16	12,10	9,77	11,3	9,1

Annex 1.2.12: “Climate Data“ Worksheet

Parameters for PHPP Calculated Ground Temperatures:	
Phase Shift Months	2,00
Damping	-1,05
Depth m	3,32
Shift of Average Temperature K	1,60

Month	1	2	3	4	5	6
Days	31	28	31	30	31	30
PL - Strefa II (Poznan/Pila)	Latitude:	52,4	Longitude ° East	16,9	Altitude m	97
Ambient Temp	-1,0	-1,0	3,3	7,6	13,5	16,6
North	19,379	21,512	46,900	70,721	86,539	104,166
East	22,624	26,219	63,803	87,704	120,847	128,500
South	46,632	43,624	86,490	93,453	118,333	117,985
West	21,986	25,533	56,429	81,626	110,467	120,680
Global	27,962	31,503	73,137	99,324	155,522	150,700
Dew Point	-3,800	-3,200	-0,500	2,600	6,600	10,400
Sky Temp	-11,100	-10,300	-7,100	-1,600	4,700	8,500
Ground Temp	7,8	6,7	6,8	8,0	10,0	13,1

7	8	9	10	11	12	Heating Load		Cooling Load
31	31	30	31	30	31	Weather 1	Weather 2	Radiation
	Daily Temperature Swing Summer (K)		10,6	Radiation Data:	kWh/(m²*month)	Radiation: W/m²		W/m²
17,5	17,9	12,9	6,6	3,8	0,7	-11,0	-5,0	25,0
97,906	83,293	57,424	35,668	18,650	15,698	10	5	110
125,179	103,247	64,857	42,172	20,378	16,388	15	10	230
115,458	109,926	78,571	64,958	30,334	23,201	30	10	220
113,806	99,320	66,702	43,718	20,464	16,008	15	10	220
146,603	124,786	76,655	51,570	22,963	17,769	25	10	350
11,700	11,700	9,100	5,800	1,400	-1,800			
9,600	10,200	5,200	-2,800	-3,800	-7,600			15,7
15,1	16,2	15,4	14,2	12,1	9,8	6,7	6,7	16,2


Solar radiation + Ambient temperature
kWh/(m²month)
°C
Month
North
East
South
West
Global
Ambient Temp
180
160
140
120
100
80
60
40
20
0
20
15
10
5
0
-5
1
2
3
4
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11
12

Annex 1.2.13: “Internal Heat Gains“ Worksheet

Passive House verification

INTERNAL HEAT GAINS

Building: Passive House

Utilisation Pattern: Dwelling | 2,10 | W/m²

Type of Values Used: Standard

No entry required | | W/m²

Calculation Internal Heat Household			
Persons	4,0	P	
Living Area	106	m²	
Heating Demand	29	kWh/(m²a)	
Heating Period	218	d/a	

Application	1 Existing (1/0), or number of people	2 In the Thermal Envelope (1/0)	3 Norm Consumption		4 Utilization Factor	5 Frequency		6 Useful Energy (kWh/a)		7 Included in Electricity Balance?		8 Availability		9 Used During Time Period (kh/a)		10 Internal Heat Source (W)
Dishwashing	1	1	1,1	kWh/Use	1,00	65	/(P*a)	286	*			0,30	/	8,76	=	10
Clothes Washing	1	1	1,1	kWh/Use	1,00	57	/(P*a)	251	*			0,30	/	8,76	=	9
Clothes drying with: Clothesline	1	1	3,5	kWh/Use	0,88	57	/(P*a)	0	*			1,00	/	8,76	=	0
		1	0,0					0				0,80				
Energy consumed by evaporation	1	1	-3,1	kWh/Use	0,60	57	/(P*a)	-428	* (1-	0	) *	1,00	/	8,76	=	-49
Refrigerating	0	1	0,8	kWh/d	1,00	365	d/a	0	*			1,00	/	8,76	=	0
Freezing	0	1	0,9	kWh/d	1,00	365	d/a	0	*			1,00	/	8,76	=	0
or Combination	1	1	1,0	kWh/d	1,00	365	d/a	365	*			1,00	/	8,76	=	42
Cooking	1	1	0,3	kWh/Use	1,00	500	/(P*a)	500	*			0,50	/	8,76	=	29
Lighting	1	1	20,8	W	1,00	2,9	kh/(P*a)	241	*			1,00	/	8,76	=	28
Consumer Electronics	1	1	80,0	W	1,00	0,55	kh/(P*a)	176	*			1,00	/	8,76	=	20
Household Appliances/Other	1	1	50,0	kWh	1,00	1,0	/(P*a)	200	*			1,00	/	8,76	=	23
Auxiliary Appliances (cf. Aux Electricity Sheet)															=	2
Other Applications (cf. Electricity Sheet)	0	0,0						0	*			0	/	8,76	=	0
Persons	4	1	80,0	W/P	1,00	8,76	kh/a	2803	*			0,55	/	8,76	=	176
Cold Water	4	1	-5,0	W/P	1,00	8,76	kh/a								=	-20
Evaporation	4	1	-25,0	W/P	1,00	8,76	kh/a	-876	*			1,00	/	8,76	=	-100
Total														W		**168**
Specific Demand														W/m²		**1,58**
Heat Available From Internal Sources										218	d/a			kWh/(m²a)		**8,3**

Annex 2.1

Thermal transmittance of building envelope elements

1. Thermal transmittance of the exterior wall covered with plaster ($U_{exterior.wall.plaster}$):

Thermal resistance of the exterior wall covered with plaster ($R_{exterior.wall.plaster}$):

$$R_{exterior.wall.plaster} := 0.04\frac{m^2\cdot K}{W} + \frac{0.002m}{0.8\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{0.238\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 10.922\frac{m^2\cdot K}{W}$$

$$U_{exterior.wall.plaster} := \frac{1}{R_{exterior.wall.plaster}} = 0.092\frac{W}{m^2\cdot K}$$

$$U_{t.exterior.wall.plaster} := U_{exterior.wall.plaster}$$

$$U_{t.exterior.wall.plaster} = 0.092\frac{W}{m^2\cdot K}$$

2. Thermal transmittance of the exterior wall covered with panels ($U_{exterior.wall.panels}$):

Thermal resistance of the exterior wall covered with panels ($R_{exterior.wall.panels}$):

$$R_{exterior.wall.panels} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.130\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{0.238\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 11.035\frac{m^2\cdot K}{W}$$

$$U_{exterior.wall.panels} := \frac{1}{R_{exterior.wall.panels}} = 0.091\frac{W}{m^2\cdot K}$$

$$U_{t.exterior.wall.panels} := U_{exterior.wall.panels}$$

$$U_{t.exterior.wall.panels} = 0.091\frac{W}{m^2\cdot K}$$

3. Thermal transmittance of window (U_{window}):

$$U_{window} := 0.72\frac{W}{m^2\cdot K}$$

4. Thermal transmittance of the exterior wall - lintel (covered with plaster) ($U_{lintel.exterior.wall.plaster}$):

Thermal resistance of the exterior wall - lintel (covered with plaster) ($R_{lintel.exterior.wall.plaster}$):

$$R_{lintel.exterior.wall.plaster} := 0.04\frac{m^2\cdot K}{W} + \frac{0.002m}{0.8\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{1.52\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 10.036\frac{m^2\cdot K}{W}$$

$$U_{lintel.exterior.wall.plaster} := \frac{1}{R_{lintel.exterior.wall.plaster}} = 0.1\cdot\frac{W}{m^2\cdot K}$$

5. Thermal transmittance of the exterior wall - lintel (covered with panels) ($U_{lintel.exterior.wall.panels}$):

Thermal resistance of the exterior wall - lintel (covered with panels) ($R_{lintel.exterior.wall.panels}$):

$$R_{lintel.exterior.wall.panels} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.13\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{1.52\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 10.149\frac{m^2\cdot K}{W}$$

$$U_{lintel.exterior.wall.panels} := \frac{1}{R_{lintel.exterior.wall.panels}} = 0.099\frac{W}{m^2\cdot K}$$

6. Thermal transmittance of the exterior wall - Spine beam (covered with plaster) ($U_{spine.exterior.wall.plaster}$):

Thermal resistance of the exterior wall - Spine beam (covered with plaster) ($R_{spine.exterior.wall.plaster}$):

$$R_{spine.exterior.wall.plaster} := 0.04\frac{m^2\cdot K}{W} + \frac{0.002m}{0.08\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{1.7\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 10.041\frac{m^2\cdot K}{W}$$

$$U_{spine.exterior.wall.plaster} := \frac{1}{R_{spine.exterior.wall.plaster}} = 0.1\cdot\frac{W}{m^2\cdot K}$$

7. Thermal transmittance of the exterior wall - Spine beam (covered with panels) ($U_{spine.exterior.wall.panels}$):

Thermal resistance of the exterior wall - Spine beam (covered with panels) ($R_{spine.exterior.wall.panels}$):

$$R_{spine.exterior.wall.panels} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.13\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{1.7\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 10.131\frac{m^2\cdot K}{W}$$

8. Thermal transmittance of the exterior wall - Pillar (covered with plaster) ($U_{pillar.exterior.wall.plaster}$):

Thermal resistance of the exterior wall - Pillar (covered with plaster) ($R_{pillar.exterior.wall.plaster}$):

$$R_{pillar.exterior.wall.plaster} := 0.04\frac{m^2\cdot K}{W} + \frac{0.002m}{0.8\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{1.7\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 10.018\frac{m^2\cdot K}{W}$$

$$U_{pillar.exterior.wall.plaster} := \frac{1}{R_{pillar.exterior.wall.plaster}} = 0.1\frac{W}{m^2\cdot K}$$

9. Thermal transmittance of the exterior wall - Pillar (covered with panels) ($U_{pillar.exterior.wall.panels}$):

Thermal resistance of the exterior wall - Pillar (covered with panels) ($R_{pillar.exterior.wall.panels}$):

$$R_{pillar.exterior.wall.panels} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.13\frac{W}{m\cdot K}} + \frac{0.3m}{0.031\frac{W}{m\cdot K}} + \frac{0.25m}{1.7\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 10.131\frac{m^2\cdot K}{W}$$

$$U_{pillar.exterior.wall.panels} := \frac{1}{R_{pillar.exterior.wall.panels}} = 0.099\frac{W}{m^2\cdot K}$$

10. Thermal transmittance of the roof (U_{roof}):

Thermal resistance of the variable part of the roof ($R_{variable.shape.}$):

$$R_{variable.shape} := \frac{0.3m}{0.28\frac{W}{m\cdot K}} = 1.071\frac{m^2\cdot K}{W}$$

Thermal resistance of the constant part of the roof ($R_{constant.shape}$):

$$R_{constant.shape} := 0.10\frac{m^2\cdot K}{W} + \frac{0.025m}{0.23\frac{W}{m\cdot K}} + \frac{0.15m}{0.03\frac{W}{m\cdot K}} + \frac{0.24m}{0.649\frac{W}{m\cdot K}} + \frac{0.1m}{0.77\frac{W}{m\cdot K}} + \\ + \frac{0.15m}{0.031\frac{W}{m\cdot K}} + 0.04\frac{m^2\cdot K}{W} = 10.587\frac{m^2\cdot K}{W}$$

Thermal transmittance of the roof (U_{roof}):

$$U_{roof} := \frac{1}{R_{variable.shape}}\ln\left(1 + \frac{R_{variable.shape}}{R_{constant.shape}}\right) = 0.09\frac{W}{m^2\cdot K}$$

Annex 2.2

Heat transfer coefficients

1. Calculation of direct heat transfer coefficient by transmission to the external environment (H_D):

1.1. Direct heat transfer coefficient by transmission through the area of exterior walls to the external environment - plaster ($H_{D.walls.plaster}$):

$$H_{D.walls.} := \left(6.3m^2 + 23.3m^2 + 37.7m^2 + 28.1m^2\right)\cdot\left(0.092\frac{W}{m^2K}\right) + \left(7.2m^2 + 8.3m^2 + 0.1m^2 + 6.9m^2\right)\cdot\left(0.091\frac{W}{m^2K}\right) + \left(1.6m^2 + 0.3m^2\right)\cdot\left(0.1\frac{W}{m^2K}\right) + \left(3.2m^2 + 0.3m^2\right)\cdot\left(0.099\frac{W}{m^2K}\right) + 0.7m^2\cdot\left(0.1\frac{W}{m^2\cdot K}\right) + 1.2m^2\cdot\left(0.099\frac{W}{m^2\cdot K}\right) + 2.9m^2\cdot\left(0.1\frac{W}{m^2\cdot K}\right)$$

$$H_{D.walls.} := 11.84\frac{W}{K}$$

1.2. Direct heat transfer coefficient by transmission through the thermal bridges in stair slab to the external environment ($H_{D.stairs.T}$):

$$H_{D.stairs.T} := 3.6m\cdot 0.001\frac{W}{m\cdot K} = 3.6\times 10^{-3}\cdot\frac{W}{K}$$

1.3. Direct heat transfer coefficient by transmission through the thermal bridges in floor slab to the external environment ($H_{D.floor.T}$):

$$H_{D.floor.T} := 30.91m\cdot(-0.092)\cdot\frac{W}{m\cdot K} = -2.844\frac{W}{K}$$

1.4. Direct heat transfer coefficient by transmission through the thermal bridges in spine beam to the external environment ($H_{D.beamT}$):

$$H_{D.beam.T} := 30.91m\cdot 0.023\frac{W}{m\cdot K} = 0.711\frac{W}{K}$$

1.5. Direct heat transfer coefficient by transmission through the thermal bridges in the exterior walls to the external environment ($H_{D.walls.thermal.bridges}$):

Thermal bridges at the corners between exterior walls:

$$H_{D.corner.exterior.walls.T} := 4\cdot 5.34m\cdot(-0.054)\frac{W}{m\cdot K} = -1.153\cdot\frac{W}{K}$$

1.6. Direct heat transfer coefficient by transmission through the area of windows and entrance door to the external environment ($H_{D.windows.door}$):

$$H_{D.windows} := \left(10.7m^2 + 3.1m^2 + 0.6m^2 + 10.7m^2 + 3.1m^2 + 2.9m^2\right)\cdot\left(0.58\frac{W}{m^2K}\right) = 18.038m^2\frac{W}{m^2K}$$

$$H_{D.door} := \left(5.58m^2\right)\cdot\left(0.77\frac{W}{m^2K}\right) = 4.297m^2\frac{W}{m^2K}$$

$$H_{D.windows.door} := H_{D.windows} + H_{D.door} = 22.335\frac{W}{K}$$

1.7. Direct heat transfer coefficient by transmission through the thermal bridges in windows and entrance door to the external environment ($H_{D.windows.door.T}$):

$$H_{D.windows.door.T} := 89m\cdot 0.021\frac{W}{m\cdot K} = 1.869\frac{W}{K}$$

1.8. Direct heat transfer coefficient by transmission through the area of roof to the external environment ($H_{D.roof}$):

$$H_{D.roof} := \left(56.44m^2\cdot 0.088\frac{W}{m^2K}\right) = 4.967\frac{W}{K}$$

1.9. Direct heat transfer coefficient by transmission through the thermal bridges in roof to the external environment ($H_{D.roof.exterior.wall.T}$):

$$H_{D.roof.exterior.wall.T} := 30.91m\cdot(-0.021)\cdot\frac{W}{m\cdot K} = -0.649\frac{W}{K}$$

$$H_{D.walls.} + H_{D.stairs.T} + H_{D.floor.T} + H_{D.beam.T} + H_{D.corner.exterior.walls.T} + \left(H_{D.windows.door} + H_{D.windows.door.T} +\right.$$

$$H_D := 37.079\frac{W}{K}$$

2. Calculation of heat transfer coefficient by transmission to the ground (H_g):

Floor slab area (TFA): $TFA = 69m^2$ Perimeter of the floor (P): $P := 34.4m$

Characteristic dimension of floor (B):

$$B := \frac{TFA}{\frac{P}{2}} = 4.012\,m$$

Thermal resistance of the floor (R_{floor}):

$$R_{floor} := \frac{0.1m}{0.77\frac{W}{m \cdot K}} + \frac{0.05m}{1.3\frac{W}{m \cdot K}} + \frac{0.01m}{0.18\frac{W}{m \cdot K}} + \frac{0.3m}{0.031\frac{W}{m \cdot K}} + \left(\frac{0.05m}{1.3\frac{W}{m \cdot K}}\right) + \frac{0.01m}{1.7\frac{W}{m \cdot K}} \qquad R_{floor} := 9.93\frac{m^2 \cdot K}{W}$$

Total equivalent thickness slab-on-ground floor (d_t):

$$w := 0.52m$$

$$\lambda := 2\frac{W}{m \cdot K}$$

It was assumed the sand under the ground floor

$$R_{si.f} := 0.17\frac{m^2 \cdot K}{W} \qquad R_{se.f} := 0 \cdot \frac{m^2 \cdot K}{W}$$

$$d_t := w + \lambda \cdot \left(R_{si.f} + R_{floor} + R_{se.f}\right) = 20.72m$$

$$d_t > B$$

The floor is well insulated.

Thermal transmittance of floor (U_f):

$$U_f := \frac{\lambda}{0.475B + d_t} = 0.088\frac{W}{m^2 \cdot K}$$

Heat transfer coefficient by transmission through the ground floor area to the ground ($H_{g.A}$):

$$H_{g.A} := U_f \cdot TFA = 6.099\frac{W}{K}$$

Heat transfer coefficient by transmission through the thermal bridges in the ground floor to the ground ($H_{g.T}$):

$$H_{g.T} := -0.092\frac{W}{m \cdot K} \cdot P = -3.165\frac{W}{K}$$

Heat transfer coefficient by transmission through the ground floor to the ground (H_g)

$$H_g := 0.6\left(H_{g.A} + H_{g.T}\right) = 1.761\frac{W}{K}$$

0.6 - reduction factor

3. Transmission heat transfer coefficient ($H_{tr.adj}$)

$$H_{tr.adj} := H_D + H_g = 38.84\frac{W}{K}$$

Annex 2.3

Total heat transfer by transmission

Set point-temperature for the home for heating ($\theta_{int.set.H}$):

$\theta_{int.set.H} := 20.441°C$

Temperatures of external environment for each month ($\theta_{\theta.i}$):

$\theta_{\theta.01} := -2.0°C$

$\theta_{\theta.02} := -1.0°C$

$\theta_{\theta.03} := 2.7°C$

$\theta_{\theta.04} := 7.6°C$

$\theta_{\theta.05} := 13.3°C$

$\theta_{\theta.09} := 13.4°C$

$\theta_{\theta.10} := 8.8°C$

$\theta_{\theta.11} := 3.8°C$

$\theta_{\theta.12} := -0.1°C$

Duration of each month (calculations step), (t_i):

$t_{01} := 2678400s$

$t_{02} := 2419200s$

$t_{03} := 2678400s$

$t_{04} := 2592000s$

$t_{05} := 2678400s$

$t_{09} := 2592000s$

$t_{10} := 2678400s$

$t_{11} := 2592000s$

$t_{12} := 2678400s$

Total heat transfer by transsmision in each month ($Q_{tr.i}$):

$$Q_{tr.01} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.01}) t_{01} = 2.334 \times 10^{9} J$$

$$Q_{tr.02} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.02}) t_{02} = 2.015 \times 10^{9} J$$

$$Q_{tr.03} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.03}) t_{03} = 1.846 \times 10^{9} J$$

$$Q_{tr.04} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.04}) t_{04} = 1.293 \times 10^{9} J$$

$$Q_{tr.05} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.05}) t_{05} = 7.429 \times 10^{8} J$$

$$Q_{tr.09} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.09}) t_{09} = 7.088 \times 10^{8} J$$

$$Q_{tr.10} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.10}) t_{10} = 1.211 \times 10^{9} J$$

$$Q_{tr.11} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.11}) t_{11} = 1.675 \times 10^{9} \cdot J$$

$$Q_{tr.12} := H_{tr.adj} \cdot (\theta_{int.set.H} - \theta_{\theta.12}) t_{12} = 2.137 \times 10^{9} \cdot J$$

Annual heat transfer by transsmision (Q_{tr}):

$$Q_{tr} := Q_{tr.01} + Q_{tr.02} + Q_{tr.03} + Q_{tr.04} + Q_{tr.05} + Q_{tr.09} + Q_{tr.10} + Q_{tr.11} + Q_{tr.12} = 1.396 \times 10^{10} J$$

Annex 2.4

Total heat transfer by ventilation

Time avarage airflow rate for compartments ($q_{ve.i}$):

$$q_{ve.livingroom} := 50\frac{m^3}{h} = 0.014\frac{m^3}{s}$$

$$q_{ve.kitchen} := 50\frac{m^3}{h} = 0.014\frac{m^3}{s} \qquad q_{ve.bathroom} := 30\frac{m^3}{h} = 8.333\times 10^{-3}\frac{m^3}{s}$$

$$q_{ve.bedroom} := 30\frac{m^3}{h} = 8.333\times 10^{-3}\frac{m^3}{s} \qquad q_{ve.closet} := 10\frac{m^3}{h} = 2.778\times 10^{-3}\frac{m^3}{s}$$

Supplied air condition ($q_{ve.supplied}$):

$$q_{ve.supplied} := 3q_{ve.bedroom} + 1q_{ve.livingroom} = 0.0389\frac{m^3}{s}$$

Extracted air condition ($q_{ve.extracted}$):

$$q_{ve.extracted} := q_{ve.kitchen} + 2q_{ve.bathroom} + 3\cdot q_{ve.closet} = 0.039\frac{m^3}{s}$$

$$V = 631.295m^3$$

Overall heat transfer coefficient by ventilation ($H_{ve.adj}$):

$$H_{ve.adj} := \rho_{aca}\cdot\left(b_{ve.k}\cdot q_{ve.supplied}\right) = 46.667\frac{W}{K}$$

Heat transfer by ventilation in each month ($Q_{ve.i}$):

$$Q_{ve.01} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.01}\right)t_{01} = 2.805\times 10^{9}\,J$$

$$Q_{ve.02} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.02}\right)t_{02} = 2.421\times 10^{9}\,J$$

$$Q_{ve.03} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.03}\right)t_{03} = 2.217\times 10^{9}\,J$$

$$Q_{ve.04} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.04}\right)t_{04} = 1.553\times 10^{9}\,J$$

$$Q_{ve.05} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.05}\right)t_{05} = 8.926\times 10^{8}\,J$$

$$Q_{ve.09} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.09}\right)t_{09} = 8.517\times 10^{8}\,J$$

$$Q_{ve.10} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.10}\right)t_{10} = 1.455\times 10^{9}\,J$$

$$Q_{ve.11} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.11}\right)t_{11} = 2.013\times 10^{9}\,J$$

$$Q_{ve.12} := H_{ve.adj}\cdot\left(\theta_{int.set.H} - \theta_{\theta.12}\right)t_{12} = 2.567\times 10^{9}\,J$$

Annual heat transfer by ventilation (Q_{ve}):

$$Q_{ve} := Q_{ve.01} + Q_{ve.02} + Q_{ve.03} + Q_{ve.04} + Q_{ve.05} + Q_{ve.09} + Q_{ve.10} + Q_{ve.11} + Q_{ve.12} = 1.678\times 10^{10}\,J$$

Annex 2.5

Internal heat gains from occupants and appliances

Mean heat flow rate from occupants and appliances:

for the living room and kitchen:

$$\phi_{int.Oc.1} := 9 \cdot \frac{W}{m^2}$$

for bedrooms:

$$\phi_{int.Oc.2} := 3 \cdot \frac{W}{m^2}$$

Areas of compartments:

$$living_{room.and.kitchen} := 28.69\,m^2$$

$$bedroom_1 := 8.39\,m^2$$

$$bedroom_2 := 8.76\,m^2$$

$$bedroom_3 := 12.91\,m^2$$

Heat flow rate from occupants and appliances for the living room and kitchen in each month ($\phi_{int.Oc.A.1.i}$):

$$\phi_{int.Oc.1.01} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{01} = 6.916 \times 10^8\ J$$

$$\phi_{int.Oc.1.02} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{02} = 6.247 \times 10^8\ J$$

$$\phi_{int.Oc.1.03} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{03} = 6.916 \times 10^8\ J$$

$$\phi_{int.Oc.1.04} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{04} = 6.693 \times 10^8\ J$$

$$\phi_{int.Oc.1.05} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{05} = 6.916 \times 10^8\ J$$

$$\phi_{int.Oc.1.09} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{09} = 6.693 \times 10^8\ J$$

$$\phi_{int.Oc.1.10} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{10} = 6.916 \times 10^8\ J$$

$$\phi_{int.Oc.1.11} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{11} = 6.693 \times 10^8\ J$$

$$\phi_{int.Oc.1.12} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{12} = 6.916 \times 10^8\ J$$

Heat flow rate from occupants and appliances for bedrooms in each month ($\phi_{int.Oc.A.2.i}$):

$$\phi_{int.Oc.2.01} := \phi_{int.Oc.2} \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{01} = 2.415 \times 10^8\ J$$

$$\phi_{int.Oc.2.02} := \phi_{int.Oc.2} \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{02} = 2.182 \times 10^8\ J$$

$$\phi_{int.Oc.2.03} := \phi_{int.Oc.2} \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{03} = 2.415 \times 10^8\ J$$

$$\phi_{int.Oc.2.04} := \phi_{int.Oc.2} \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{04} = 2.337 \times 10^8\ J$$

$$\phi_{int.Oc.2.05} := \phi_{int.Oc.2} \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{05} = 2.415 \times 10^8\ J$$

$$\phi_{int.Oc.2.09} := \phi_{int.Oc.2} \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{09} = 2.337 \times 10^8\ J$$

$$\phi_{int.Oc.2.10} := \phi_{int.Oc.2} \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{10} = 2.415 \times 10^8\ J$$

$$\phi_{int.Oc.2.11} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{11} = 2.337 \times 10^8 \, J$$

$$\phi_{int.Oc.2.12} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{12} = 2.415 \times 10^8 \, J$$

Annual heat flow rate from occupants and appliances for the home ($\phi_{int.Oc.A}$):

$$\begin{aligned}\phi_{int.Oc} := {} & \phi_{int.Oc.1.01} + \phi_{int.Oc.1.02} + \phi_{int.Oc.1.03} + \phi_{int.Oc.1.04} + \phi_{int.Oc.1.05} + \phi_{int.Oc.1.09} \cdots \\ & + \phi_{int.Oc.1.10} + \phi_{int.Oc.1.11} + \phi_{int.Oc.1.12} + \phi_{int.Oc.2.01} + \phi_{int.Oc.2.02} + \phi_{int.Oc.2.03} \cdots \\ & + \phi_{int.Oc.2.04} + \phi_{int.Oc.2.05} + \phi_{int.Oc.2.09} + \phi_{int.Oc.2.10} + \phi_{int.Oc.2.11} + \phi_{int.Oc.2.12}\end{aligned} = 8.218 \times 10^9 \, J$$

Annex 2.6

Internal heat gains from lighting

Heat flow rate from lighting in each month ($\phi_{int.L.}$):

$$\phi_{int.L.01} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{01}\cdot t_{01} = 2.143\times 10^{9}\ J$$

$$\phi_{int.L.02} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{02}\cdot t_{02} = 1.935\times 10^{9}\ J$$

$$\phi_{int.L.03} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{03}\cdot t_{03} = 1.714\times 10^{9}\ J$$

$$\phi_{int.L.04} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{04}\cdot t_{04} = 1.244\times 10^{9}\ J$$

$$\phi_{int.L.05} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{05}\cdot t_{05} = 1.286\times 10^{9}\ J$$

$$\phi_{int.L.09} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{09}\cdot t_{09} = 1.244\times 10^{9}\ J$$

$$\phi_{int.L.10} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{10}\cdot t_{10} = 1.714\times 10^{9}\ J$$

$$\phi_{int.L.11} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{11}\cdot t_{11} = 1.659\times 10^{9}\ J$$

$$\phi_{int.L.12} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{12}\cdot t_{12} = 2.143\times 10^{9}\ J$$

Annual heat flow rate from lighting ($\phi_{int.L}$):

$$\phi_{int.L} := \phi_{int.L.01} + \phi_{int.L.02} + \phi_{int.L.03} + \phi_{int.L.04} + \phi_{int.L.05} \cdots + \phi_{int.L.09} + \phi_{int.L.10} + \phi_{int.L.11} + \phi_{int.L.12} = 1.508\times 10^{10}\ J$$

Annex 2.7

Monthly and annual heat losses and internal heat gains

Monthly heat losses by transmission and ventilation ($Q_{ht.i}$):

$$Q_{ht.01} := Q_{tr.01} + Q_{ve.01} = 5.139 \times 10^{9}\,J$$

$$Q_{ht.02} := Q_{tr.02} + Q_{ve.02} = 4.435 \times 10^{9}\,J$$

$$Q_{ht.03} := Q_{tr.03} + Q_{ve.03} = 4.063 \times 10^{9}\,J$$

$$Q_{ht.04} := Q_{tr.04} + Q_{ve.04} = 2.846 \times 10^{9}\,J$$

$$Q_{ht.05} := Q_{tr.05} + Q_{ve.05} = 1.635 \times 10^{9}\,J$$

$$Q_{ht.09} := Q_{tr.09} + Q_{ve.09} = 1.561 \times 10^{9}\,J$$

$$Q_{ht.10} := Q_{tr.10} + Q_{ve.10} = 2.666 \times 10^{9}\,J$$

$$Q_{ht.11} := Q_{tr.11} + Q_{ve.11} = 3.688 \times 10^{9}\,J$$

$$Q_{ht.12} := Q_{tr.12} + Q_{ve.12} = 4.704 \times 10^{9}\,J$$

Annual heat losses by transmission and ventilation (Q_{ht}):

$$Q_{ht} := Q_{ht.01} + Q_{ht.02} + Q_{ht.03} + Q_{ht.04} + Q_{ht.05} + Q_{ht.09} + Q_{ht.10} + Q_{ht.11} + Q_{ht.12} = 3.074 \times 10^{10}\,J$$

Monthly heat gains from occupants, appliances and lighting ($Q_{int.i}$):

$$Q_{.int.01} := \phi_{int.Oc.1.01} + \phi_{int.Oc.2.01} + \phi_{int.L.01} = 3.076 \times 10^{9}\,J$$

$$Q_{.int.02} := \phi_{int.Oc.1.02} + \phi_{int.Oc.2.02} + \phi_{int.L.02} = 2.778 \times 10^{9}\,J$$

$$Q_{.int.03} := \phi_{int.Oc.1.03} + \phi_{int.Oc.2.03} + \phi_{int.L.03} = 2.647 \times 10^{9}\,J$$

$$Q_{.int.04} := \phi_{int.Oc.1.04} + \phi_{int.Oc.2.04} + \phi_{int.L.04} = 2.147 \times 10^{9}\,J$$

$$Q_{.int.05} := \phi_{int.Oc.1.05} + \phi_{int.Oc.2.05} + \phi_{int.L.05} = 2.219 \times 10^{9}\,J$$

$$Q_{.int.09} := \phi_{int.Oc.1.09} + \phi_{int.Oc.2.09} + \phi_{int.L.09} = 2.147 \times 10^{9}\,J$$

$$Q_{.int.11} := \phi_{int.Oc.1.11} + \phi_{int.Oc.2.11} + \phi_{int.L.11} = 2.562 \times 10^{9}\,J$$

$$Q_{.int.12} := \phi_{int.Oc.1.12} + \phi_{int.Oc.2.12} + \phi_{int.L.12} = 3.076 \times 10^{9}\,J$$

Anual heat gains from occupants, appliances and lighting (Q_{int}):

$$Q_{int} := Q_{.int.01} + Q_{.int.02} + Q_{.int.03} + Q_{.int.04} + Q_{.int.05} + Q_{.int.09} + Q_{.int.10} + Q_{.int.11} + Q_{.int.12} = 2.33 \times 10^{10}\,J$$

Annex 2.8

Solar heat gains through the glazed elements

Types and areas of windows $\left(A_{window.i.k}\right)$:

$A_{window.1} := 2m \cdot 1.45m = 2.9m^2$

$A_{window.2} := 3.3m \cdot 2.35m = 7.755m^2$

$A_{window.3} := 1.4m \cdot 0.6m = 0.84m^2$

$A_{window.4} := 1m \cdot 1.45m = 1.45m^2$

$A_{window.5} := 1m \cdot 0.6m = 0.6m^2$

1. Solar heat gains through the glazed elements for the south wall:

Effective solar collecting area of glazed elements on the south wall ($A_{sol.w.south}$):

$$A_{w.south} := 2 \cdot A_{window.1} + 2 \cdot A_{window.2} = 21.31m^2$$

$$A_{sol.w.south} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.s}\right) \cdot A_{w.south} = 5.86m^2$$

Solar irradiance on the south wall for each month ($I_{sol.s.i}$) :

$\left(I_{sol.s.01} := 46.632 \frac{kW \cdot h}{m^2}\right)$ $\left(I_{sol.s.04} := 93.453 \frac{kW \cdot h}{m^2}\right)$ $\left(I_{sol.s.10} := 64.958 \frac{kW \cdot h}{m^2}\right)$

$\left(I_{sol.s.02} := 43.624 \frac{kW \cdot h}{m^2}\right)$ $\left(I_{sol.s.05} := 118.333 \frac{kW \cdot h}{m^2}\right)$ $\left(I_{sol.s.11} := 30.334 \frac{kW \cdot h}{m^2}\right)$

$\left(I_{sol.s.03} := 86.490 \frac{kW \cdot h}{m^2}\right)$ $\left(I_{sol.s.09} := 78.571 \frac{kW \cdot h}{m^2}\right)$ $\left(I_{sol.s.12} := 23.201 \frac{kW \cdot h}{m^2}\right)$

Heat flow due to thermal radiation to the sky from the glazed elements on the south wall ($\phi_{r.w.south}$):

$$\phi_{r.w.south} := R_{se.window} \cdot U_{window} \cdot A_{w.south} \cdot h_{r.window} \cdot \Delta\theta_{er} \cdot h = 0.027 kW \cdot h$$

Solar gains through the glazed elements for each month ($Q_{sol.w.south.i}$):

$$\phi_{sol.w.south.01} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.01} - F_{r.k} \cdot \phi_{r.w.south} = 273.262 kW \cdot h$$

$$Q_{sol.w.south.01} := \phi_{sol.w.south.01} = 9.837 \times 10^8 \cdot J$$

$$\phi_{sol.w.south.02} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.02} - F_{r.k} \cdot \phi_{r.w.south} = 255.634 kW \cdot h$$

$$Q_{sol.w.south.02} := \phi_{sol.w.south.02} = 9.203 \times 10^8 \cdot J$$

$$\phi_{sol.w.south.03} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.03} - F_{r.k} \cdot \phi_{r.w.south} = 506.84 kW \cdot h$$

$$Q_{sol.w.south.03} := \phi_{sol.w.south.03} = 1.825 \times 10^9 J$$

$$\phi_{sol.w.south.04} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.04} - F_{r.k} \cdot \phi_{r.w.south} = 547.644 kW \cdot h$$

$$Q_{sol.w.south.04} := \phi_{sol.w.south.04} = 1.972 \times 10^9 J$$

$$\phi_{sol.w.south.05} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.05} - F_{r.k} \cdot \phi_{r.w.south} = 693.447 kW \cdot h$$

$$Q_{sol.w.south.05} := \phi_{sol.w.south.05} = 2.496 \times 10^{9} J$$

$$\phi_{sol.w.south.09} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.09} - F_{r.k} \cdot \phi_{r.w.south} = 460.432 kW \cdot h$$

$$Q_{sol.w.south.09} := \phi_{sol.w.south.09} = 1.658 \times 10^{9} J$$

$$\phi_{sol.w.south.10} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.10} - F_{r.k} \cdot \phi_{r.w.south} = 380.657 kW \cdot h$$

$$Q_{sol.w.south.10} := \phi_{sol.w.south.10} = 1.37 \times 10^{9} J$$

$$\phi_{sol.w.south.11} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.11} - F_{r.k} \cdot \phi_{r.w.south} = 177.751 kW \cdot h$$

$$Q_{sol.w.south.11} := \phi_{sol.w.south.11} = 6.399 \times 10^{8} J$$

$$\phi_{sol.w.south.12} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.12} - F_{r.k} \cdot \phi_{r.w.south} = 135.95 kW \cdot h$$

$$Q_{sol.w.south.12} := \phi_{sol.w.south.12} = 4.894 \times 10^{8} \cdot J$$

Annual solar gains through the glazed elements for the south wall in joules ($Q_{sol.w.south}$) and in kilowatt-hours ($\phi_{sol.w.south}$):

$$\begin{aligned} Q_{sol.w.south} := {} & Q_{sol.w.south.01} + Q_{sol.w.south.02} + Q_{sol.w.south.03} + Q_{sol.w.south.04} \cdots = 1.235 \times 10^{10} J \\ & + Q_{sol.w.south.05} + Q_{sol.w.south.09} + Q_{sol.w.south.10} \cdots \\ & + Q_{sol.w.south.11} + Q_{sol.w.south.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.w.south} := {} & \phi_{sol.w.south.01} + \phi_{sol.w.south.02} + \phi_{sol.w.south.03} + \phi_{sol.w.south.04} \cdots = 3.432 \times 10^{3} \cdot kW \cdot h \\ & + \phi_{sol.w.south.05} + \phi_{sol.w.south.09} + \phi_{sol.w.south.10} \cdots \\ & + \phi_{sol.w.south.11} + \phi_{sol.w.south.12} \end{aligned}$$

2. Solar heat gains through the glazed elements for the west wall

Effective solar collecting area of glazed elements on the west wall ($A_{sol.w.west}$):

$$A_{w.west} := 2 \cdot A_{window.3} + 1 \cdot A_{window.4} = 3.13 m^{2}$$

$$A_{sol.w.west} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.w}\right) \cdot A_{w.west} = 0.876 m^{2}$$

Solar irradiance on the west wall for each month ($I_{sol.w.i}$):

$$\left(I_{sol.w.01} := 21.986\frac{kW\cdot h}{m^2}\right) \quad \left(I_{sol.w.04} := 81.626\frac{kW\cdot h}{m^2}\right) \quad \left(I_{sol.w.10} := 43.718\frac{kW\cdot h}{m^2}\right)$$

$$\left(I_{sol.w.02} := 25.533\frac{kW\cdot h}{m^2}\right) \quad \left(I_{sol.w.05} := 110.467\frac{kW\cdot h}{m^2}\right) \quad \left(I_{sol.w.11} := 20.464\frac{kW\cdot h}{m^2}\right)$$

$$\left(I_{sol.w.03} := 56.429\frac{kW\cdot h}{m^2}\right) \quad \left(I_{sol.w.09} := 66.702\frac{kW\cdot h}{m^2}\right) \quad \left(I_{sol.w.12} := 20.734\frac{kW\cdot h}{m^2}\right)$$

Heat flow due to thermal radiation to the sky from the glazed elements on the west wall ($\phi_{r.w.west}$):

$$\phi_{r.w.west} := R_{se.window}\cdot U_{window}\cdot A_{w.west}\cdot h_{r.window}\cdot \Delta\theta_{er}\cdot h = 3.966\times 10^{-3}\cdot kW\cdot h$$

Solar gains through the glazed elements for each month ($Q_{sol.w.west.i}$):

$$\phi_{sol.w.west.01} := F_{sh.o}\cdot A_{sol.w.west}\cdot I_{sol.w.01} - F_{r.k}\cdot \phi_{r.w.west} = 1.927\times 10^{4}\cdot W\cdot h$$

$$Q_{sol.w.west.01} := \phi_{sol.w.west.01} = 6.936\times 10^{7}\cdot J$$

$$\phi_{sol.w.west.02} := F_{sh.o}\cdot A_{sol.w.west}\cdot I_{sol.w.02} - F_{r.k}\cdot \phi_{r.w.west} = 2.238\times 10^{4}\cdot W\cdot h$$

$$Q_{sol.w.west.02} := \phi_{sol.w.west.02} = 8.055\times 10^{7}\, J$$

$$\phi_{sol.w.west.03} := F_{sh.o}\cdot A_{sol.w.west}\cdot I_{sol.w.03} - F_{r.k}\cdot \phi_{r.w.west} = 4.945\times 10^{4}\cdot W\cdot h$$

$$Q_{sol.w.west.03} := \phi_{sol.w.west.03} = 1.78\times 10^{8}\, J$$

$$\phi_{sol.w.west.04} := F_{sh.o}\cdot A_{sol.w.west}\cdot I_{sol.w.04} - F_{r.k}\cdot \phi_{r.w.west} = 7.154\times 10^{4}\cdot W\cdot h$$

$$Q_{sol.w.west.04} := \phi_{sol.w.west.04} = 2.575\times 10^{8}\, J$$

$$\phi_{sol.w.west.05} := F_{sh.o}\cdot A_{sol.w.west}\cdot I_{sol.w.05} - F_{r.k}\cdot \phi_{r.w.west} = 9.681\times 10^{4}\cdot W\cdot h$$

$$Q_{sol.w.west.05} := \phi_{sol.w.west.05} = 3.485\times 10^{8}\, J$$

$$\phi_{sol.w.west.09} := F_{sh.o}\cdot A_{sol.w.west}\cdot I_{sol.w.09} - F_{r.k}\cdot \phi_{r.w.west} = 5.846\times 10^{4}\cdot W\cdot h$$

$$Q_{sol.w.west.09} := \phi_{sol.w.west.09} = 2.104\times 10^{8}\, J$$

$$\phi_{sol.w.west.10} := F_{sh.o}\cdot A_{sol.w.west}\cdot I_{sol.w.10} - F_{r.k}\cdot \phi_{r.w.west} = 3.831\times 10^{4}\cdot W\cdot h$$

$$Q_{sol.w.west.10} := \phi_{sol.w.west.10} = 1.379\times 10^{8}\, J$$

$$\phi_{sol.w.west.11} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.11} - F_{r.k} \cdot \phi_{r.w.west} = 1.793 \times 10^{4} \cdot W \cdot h$$

$$Q_{sol.w.west.11} := \phi_{sol.w.west.11} = 6.456 \times 10^{7}\,J$$

$$\phi_{sol.w.west.12} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.12} - F_{r.k} \cdot \phi_{r.w.west} = 1.817 \times 10^{4} \cdot W \cdot h$$

$$Q_{sol.w.west.12} := \phi_{sol.w.west.12} = 6.541 \times 10^{7}\,J$$

Annual solar gains through the glazed elements for the west wall in joules ($Q_{sol.w.west}$) and in kilowatt-hours ($\phi_{sol.w.west}$):

$$Q_{sol.w.west} := Q_{sol.w.west.01} + Q_{sol.w.west.02} + Q_{sol.w.west.03} + Q_{sol.w.west.04} \cdots + Q_{sol.w.west.05} + Q_{sol.w.west.09} + Q_{sol.w.west.10} \cdots + Q_{sol.w.west.11} + Q_{sol.w.west.12} = 1.412 \times 10^{9}\,J$$

$$\phi_{sol.w.west} := \phi_{sol.w.west.01} + \phi_{sol.w.west.02} + \phi_{sol.w.west.03} + \phi_{sol.w.west.04} \cdots + \phi_{sol.w.west.05} + \phi_{sol.w.west.09} + \phi_{sol.w.west.10} \cdots + \phi_{sol.w.west.11} + \phi_{sol.w.west.12} = 392.31\,kW \cdot h$$

3. Solar heat gains through the glazed elements for the north wall

Effective solar collecting area of glazed elements on the north wall ($A_{sol.w.north}$):

$$A_{w.north} := 1 \cdot A_{window.4} + 2 \cdot A_{window.3} = 3.13\,m^{2}$$

$$A_{sol.w.north} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.n}\right) \cdot A_{w.north} = 0.861\,m^{2}$$

Solar irradiance on the north wall for each month ($I_{sol.n.01}$):

$$\left(I_{sol.n.01} := 19.379\frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.n.04} := 70.721\frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.n.10} := 35.688\frac{kW \cdot h}{m^{2}}\right)$$

$$\left(I_{sol.n.02} := 21.512\frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.n.05} := 86.539\frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.n.11} := 18.650\frac{kW \cdot h}{m^{2}}\right)$$

$$\left(I_{sol.n.03} := 46.900\frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.n.09} := 57.424\frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.n.12} := 15.698\frac{kW \cdot h}{m^{2}}\right)$$

Heat flow due to thermal radiation to the sky from the glazed elements on the north wall ($\phi_{r.w.north}$):

$$\phi_{r.w.north} := R_{se.window} \cdot U_{window} \cdot A_{w.north} \cdot h_{r.window} \cdot \Delta\theta_{er} \cdot h = 3.966 \times 10^{-3} \cdot kW \cdot h$$

Solar gains through the glazed elements for each month ($Q_{sol.w.north.i}$):

$\phi_{sol.w.north.01} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.01} - F_{r.k} \cdot \phi_{r.w.north} = 16.678\,kW \cdot h$

$Q_{sol.w.north.01} := \phi_{sol.w.north.01} = 6.004 \times 10^{7}\,J$

$\phi_{sol.w.north.02} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.02} - F_{r.k} \cdot \phi_{r.w.north} = 18.514\,kW \cdot h$

$Q_{sol.w.north.02} := \phi_{sol.w.north.02} = 6.665 \times 10^{7}\,J$

$\phi_{sol.w.north.03} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.03} - F_{r.k} \cdot \phi_{r.w.north} = 40.367\,kW \cdot h$

$Q_{sol.w.north.03} := \phi_{sol.w.north.03} = 1.453 \times 10^{8}\,J$

$\phi_{sol.w.north.04} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.04} - F_{r.k} \cdot \phi_{r.w.north} = 60.871\,kW \cdot h$

$Q_{sol.w.north.04} := \phi_{sol.w.north.04} = 2.191 \times 10^{8}\,J$

$\phi_{sol.w.north.05} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.05} - F_{r.k} \cdot \phi_{r.w.north} = 74.486\,kW \cdot h$

$Q_{sol.w.north.05} := \phi_{sol.w.north.05} = 2.682 \times 10^{8}\,J$

$\phi_{sol.w.north.09} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.09} - F_{r.k} \cdot \phi_{r.w.north} = 49.426\,kW \cdot h$

$Q_{sol.w.north.09} := \phi_{sol.w.north.09} = 1.779 \times 10^{8}\,J$

$\phi_{sol.w.north.10} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.10} - F_{r.k} \cdot \phi_{r.w.north} = 30.716\,kW \cdot h$

$Q_{sol.w.north.10} := \phi_{sol.w.north.10} = 1.106 \times 10^{8}\,J$

$\phi_{sol.w.north.11} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.11} - F_{r.k} \cdot \phi_{r.w.north} = 16.051\,kW \cdot h$

$Q_{sol.w.north.11} := \phi_{sol.w.north.11} = 5.778 \times 10^{7}\,J$

$\phi_{sol.w.north.12} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.12} - F_{r.k} \cdot \phi_{r.w.north} = 13.51\,kW \cdot h$

$Q_{sol.w.north.12} := \phi_{sol.w.north.12} = 4.864 \times 10^{7}\,J$

Annual solar gains through the glazed elements for the north wall in joules ($Q_{sol.w.north}$) and in kilowatt-hours ($\phi_{sol.w.north}$):

$$Q_{sol.w.north} := Q_{sol.w.north.01} + Q_{sol.w.north.02} + Q_{sol.w.north.03} + Q_{sol.w.north.04} \cdots + Q_{sol.w.north.05} + Q_{sol.w.north.09} + Q_{sol.w.north.10} \cdots + Q_{sol.w.north.11} + Q_{sol.w.north.12} = 1.154 \times 10^{9}\,J$$

$$\phi_{sol.w.north} := \phi_{sol.w.north.01} + \phi_{sol.w.north.02} + \phi_{sol.w.north.03} + \phi_{sol.w.north.04} \cdots + \phi_{sol.w.north.05} + \phi_{sol.w.north.09} + \phi_{sol.w.north.10} \cdots + \phi_{sol.w.north.11} + \phi_{sol.w.north.12} = 320.621\,kW \cdot h$$

4. Solar heat gains through the glazed elements for the east wall

Effective solar collecting area of glazed elements on the north wall ($A_{sol.w.east}$):

$$A_{w.east} := 2 \cdot A_{window.4} + 1 \cdot A_{window.5} = 3.5\,m^{2}$$

$$A_{sol.w.east} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.e}\right) \cdot A_{w.east} = 0.984\,m^{2}$$

Solar irradiance on the east wall for each month ($I_{sol.e.01}$):

$$\left(I_{sol.e.01} := 22.642 \frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.e.04} := 87.704 \frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.e.10} := 42.172 \frac{kW \cdot h}{m^{2}}\right)$$

$$\left(I_{sol.e.02} := 26.219 \frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.e.05} := 120.847 \frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.e.11} := 20.378 \frac{kW \cdot h}{m^{2}}\right)$$

$$\left(I_{sol.e.03} := 63.803 \frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.e.09} := 64.857 \frac{kW \cdot h}{m^{2}}\right) \quad \left(I_{sol.e.12} := 16.388 \frac{kW \cdot h}{m^{2}}\right)$$

Heat flow due to thermal radiation to the sky from the glazed elements on the east wall ($\phi_{r.w.east}$):

$$\phi_{r.w.east} := R_{se.window} \cdot U_{window} \cdot A_{w.west} \cdot h_{r.window} \cdot \Delta\theta_{er} \cdot h = 3.966 \times 10^{-3} \cdot kW \cdot h$$

Solar gains through the glazed elements for each month ($Q_{sol.w.east.i}$):

$$\phi_{sol.w.east.01} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.01} - F_{r.k} \cdot \phi_{r.w.east} = 22.266\,kW \cdot h$$

$$Q_{sol.w.east.01} := \phi_{sol.w.east.01} = 8.016 \times 10^{7}\,J$$

$$\phi_{sol.w.east.02} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.02} - F_{r.k} \cdot \phi_{r.w.east} = 25.784\,kW \cdot h$$

$$Q_{sol.w.east.02} := \phi_{sol.w.east.02} = 9.282 \times 10^{7}\,J$$

$\phi_{sol.w.east.03} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.03} - F_{r.k} \cdot \phi_{r.w.east} = 62.748\,kW \cdot h$

$Q_{sol.w.east.03} := \phi_{sol.w.east.03} = 2.259 \times 10^{8}\,J$

$\phi_{sol.w.east.04} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.04} - F_{r.k} \cdot \phi_{r.w.east} = 86.255\,kW \cdot h$

$Q_{sol.w.east.04} := \phi_{sol.w.east.04} = 3.105 \times 10^{8}\,J$

$\phi_{sol.w.east.05} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.05} - F_{r.k} \cdot \phi_{r.w.east} = 118.851\,kW \cdot h$

$Q_{sol.w.east.05} := \phi_{sol.w.east.05} = 4.279 \times 10^{8}\,J$

$\phi_{sol.w.east.09} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.09} - F_{r.k} \cdot \phi_{r.w.east} = 63.785\,kW \cdot h$

$Q_{sol.w.east.09} := \phi_{sol.w.east.09} = 2.296 \times 10^{8}\,J$

$\phi_{sol.w.east.10} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.10} - F_{r.k} \cdot \phi_{r.w.east} = 41.474\,kW \cdot h$

$Q_{sol.w.east.10} := \phi_{sol.w.east.10} = 1.493 \times 10^{8}\,J$

$\phi_{sol.w.east.11} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.11} - F_{r.k} \cdot \phi_{r.w.east} = 20.04\,kW \cdot h$

$Q_{sol.w.east.11} := \phi_{sol.w.east.11} = 7.214 \times 10^{7}\,J$

$\phi_{sol.w.east.12} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.12} - F_{r.k} \cdot \phi_{r.w.east} = 16.116\,kW \cdot h$

$Q_{sol.w.east.12} := \phi_{sol.w.east.12} = 5.802 \times 10^{7}\,J$

Annual solar gains through the glazed elements for the east wall in joules ($Q_{sol.w.east}$) and in kilowatt-hours ($\phi_{sol.w.east}$):

$$\begin{aligned} Q_{sol.w.east} := {} & Q_{sol.w.east.01} + Q_{sol.w.east.02} + Q_{sol.w.east.03} + Q_{sol.w.east.04} \cdots = 1.646 \times 10^{9}\,J \\ & + Q_{sol.w.east.05} + Q_{sol.w.east.09} + Q_{sol.w.east.10} \cdots \\ & + Q_{sol.w.east.11} + Q_{sol.w.east.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.w.east} := {} & \phi_{sol.w.east.01} + \phi_{sol.w.east.02} + \phi_{sol.w.east.03} + \phi_{sol.w.east.04} \cdots = 457.319\,kW \cdot h \\ & + \phi_{sol.w.east.05} + \phi_{sol.w.east.09} + \phi_{sol.w.east.10} \cdots \\ & + \phi_{sol.w.east.11} + \phi_{sol.w.east.12} \end{aligned}$$

Annex 2.9

Total solar heat gains through the glazed elements

Monthly solar heat gains through the glazed elements ($Q_{sol.w.i}$):

$$Q_{sol.w.01} := Q_{sol.w.south.01} + Q_{sol.w.west.01} + Q_{sol.w.north.01} + Q_{sol.w.east.01} = 1.193 \times 10^{9}\,J$$

$$Q_{sol.w.02} := Q_{sol.w.south.02} + Q_{sol.w.west.02} + Q_{sol.w.north.02} + Q_{sol.w.east.02} = 1.16 \times 10^{9}\,J$$

$$Q_{sol.w.03} := Q_{sol.w.south.03} + Q_{sol.w.west.03} + Q_{sol.w.north.03} + Q_{sol.w.east.03} = 2.374 \times 10^{9}\,J$$

$$Q_{sol.w.04} := Q_{sol.w.south.04} + Q_{sol.w.west.04} + Q_{sol.w.north.04} + Q_{sol.w.east.04} = 2.759 \times 10^{9}\,J$$

$$Q_{sol.w.05} := Q_{sol.w.south.05} + Q_{sol.w.west.05} + Q_{sol.w.north.05} + Q_{sol.w.east.05} = 3.541 \times 10^{9}\,J$$

$$Q_{sol.w.09} := Q_{sol.w.south.09} + Q_{sol.w.west.09} + Q_{sol.w.north.09} + Q_{sol.w.east.09} = 2.276 \times 10^{9}\,J$$

$$Q_{sol.w.10} := Q_{sol.w.south.10} + Q_{sol.w.west.10} + Q_{sol.w.north.10} + Q_{sol.w.east.10} = 1.768 \times 10^{9}\,J$$

$$Q_{sol.w.11} := Q_{sol.w.south.11} + Q_{sol.w.west.11} + Q_{sol.w.north.11} + Q_{sol.w.east.11} = 8.344 \times 10^{8}\,J$$

$$Q_{sol.w.12} := Q_{sol.w.south.12} + Q_{sol.w.west.12} + Q_{sol.w.north.12} + Q_{sol.w.east.12} = 6.615 \times 10^{8}\,J$$

Annual solar heat gains through the glazed elements in joules ($Q_{sol.w.TOTAL.joules}$) in kilowatt-hours ($Q_{sol.w.TOTAL.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{sol.w.TOTAL.kWh.m2}$):

$$\begin{aligned} Q_{sol.w.TOTAL.joules} := {} & Q_{sol.w.01} + Q_{sol.w.02} + Q_{sol.w.03} + Q_{sol.w.04} \cdots = 1.657 \times 10^{10}\,J \\ & + Q_{sol.w.05} + Q_{sol.w.09} + Q_{sol.w.10} \cdots \\ & + Q_{sol.w.11} + Q_{sol.w.12} \end{aligned}$$

$$Q_{sol.w.TOTAL.kWh} := Q_{sol.w.TOTAL.joules} = 4.602 \times 10^{3} \cdot kW \cdot h$$

$$Q_{sol.w.TOTAL.kWh.m2} := \frac{Q_{sol.w.TOTAL.joules}}{A_{conditioned.area}} = 43.373 \frac{kW \cdot h}{m^{2}}$$

Annex 2.10

Solar heat gains through the opaque building envelope - walls

1. Solar heat gains through the south exterior wall

Effective solar collecting area of the south wall ($A_{sol.W.south}$):

$$A_{W.south} := 37.09m^2 - (2 \cdot A_{window.1} + 2 \cdot A_{window.2}) = 15.78m^2$$

$$A_{sol.W.south} := \alpha_{s.c} \cdot R_{se} \cdot U_{exterior.wall} \cdot A_{W.south} = 0.063m^2$$

Solar irradiance on the south wall for each month ($I_{sol.s.i}$):

The same as for south-oriented windows

Heat flow due to thermal radiation to the sky from the south wall ($\phi_{r.W.south}$):

$$\phi_{r.W.south} := R_{se} \cdot U_{exterior.wall} \cdot A_{W.south} \cdot h_{r.wall} \cdot \Delta\theta_{er} \cdot h = 4.437 \times 10^{-3} \cdot kW \cdot h$$

Solar gains through the south wall for each month ($Q_{sol.W.south.i}$):

$$\phi_{sol.W.south.01} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.01} - F_{r.k} \cdot \phi_{r.W.south} = 2.924 kW \cdot h$$

$$Q_{sol.W.south.01} := \phi_{sol.W.south.01} = 1.052 \times 10^7 J$$

$$\phi_{sol.W.south.02} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.02} - F_{r.k} \cdot \phi_{r.W.south} = 2.735 kW \cdot h$$

$$Q_{sol.W.south.02} := \phi_{sol.W.south.02} = 9.845 \times 10^6 J$$

$$\phi_{sol.W.south.03} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.03} - F_{r.k} \cdot \phi_{r.W.south} = 5.424 kW \cdot h$$

$$Q_{sol.W.south.03} := \phi_{sol.W.south.03} = 1.953 \times 10^7 J$$

$$\phi_{sol.W.south.04} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.04} - F_{r.k} \cdot \phi_{r.W.south} = 5.861 kW \cdot h$$

$$Q_{sol.W.south.04} := \phi_{sol.W.south.04} = 2.11 \times 10^7 J$$

$$\phi_{sol.W.south.05} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.05} - F_{r.k} \cdot \phi_{r.W.south} = 7.422 kW \cdot h$$

$$Q_{sol.W.south.05} := \phi_{sol.W.south.05} = 2.672 \times 10^7 J$$

$$\phi_{sol.W.south.09} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.09} - F_{r.k} \cdot \phi_{r.W.south} = 4.927 kW \cdot h$$

$$Q_{sol.W.south.09} := \phi_{sol.W.south.09} = 1.774 \times 10^7 J$$

$$\phi_{sol.W.south.10} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.10} - F_{r.k} \cdot \phi_{r.W.south} = 4.073\,kW \cdot h$$

$$Q_{sol.W.south.10} := \phi_{sol.W.south.10} = 1.466 \times 10^{7}\,J$$

$$\phi_{sol.W.south.11} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.11} - F_{r.k} \cdot \phi_{r.W.south} = 1.901\,kW \cdot h$$

$$Q_{sol.W.south.11} := \phi_{sol.W.south.11} = 6.844 \times 10^{6}\,J$$

$$\phi_{sol.W.south.12} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.12} - F_{r.k} \cdot \phi_{r.W.south} = 1.453\,kW \cdot h$$

$$Q_{sol.W.south.12} := \phi_{sol.W.south.12} = 5.232 \times 10^{6}\,J$$

Annual solar gains through the south wall in joules ($Q_{sol.W.south}$) and in kilowatt-hours ($\phi_{sol.W.south}$):

$$Q_{sol.W.south} := Q_{sol.W.south.01} + Q_{sol.W.south.02} + Q_{sol.W.south.03} + Q_{sol.W.south.04} \cdots + Q_{sol.W.south.05} + Q_{sol.W.south.09} + Q_{sol.W.south.10} \cdots + Q_{sol.W.south.11} + Q_{sol.W.south.12} = 1.322 \times 10^{8}\,J$$

$$\phi_{sol.W.south} := \phi_{sol.W.south.01} + \phi_{sol.W.south.02} + \phi_{sol.W.south.03} + \phi_{sol.W.south.04} \cdots + \phi_{sol.W.south.05} + \phi_{sol.W.south.09} + \phi_{sol.W.south.10} \cdots + \phi_{sol.W.south.11} + \phi_{sol.W.south.12} = 36.721\,kW \cdot h$$

2. Solar heat gains through the west exterior wall

Effective solar collecting area of the west wall ($A_{sol.W.west}$):

$$A_{W.west} := 45.42\,m^{2} - \left(2 \cdot A_{window.3} + 1 \cdot A_{window.4} + A_{door.1}\right) = 39.47\,m^{2}$$

$$A_{sol.W.west} := \alpha_{s.c} \cdot R_{se} \cdot U_{exterior.wall} \cdot A_{W.west} = 0.157\,m^{2}$$

Solar irradiance on the west wall for each month ($I_{sol.w.i}$):

The same as for west-oriented windows

Heat flow due to thermal radiation to the sky from the west wall ($\phi_{r.W.west}$):

$$\phi_{r.W.west} := R_{se} \cdot U_{exterior.wall} \cdot A_{W.west} \cdot h_{r.wall} \cdot \Delta\theta_{er} \cdot h = 0.011\,kW \cdot h$$

Solar gains through the west wall for each month ($Q_{sol.W.west.i}$):

$$\phi_{sol.W.west.01} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.01} - F_{r.k} \cdot \phi_{r.W.west} = 3.445 \, kW \cdot h$$

$$Q_{sol.W.west.01} := \phi_{sol.W.west.01} = 1.24 \times 10^{7} \, J$$

$$\phi_{sol.W.west.02} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.02} - F_{r.k} \cdot \phi_{r.W.west} = 4.001 \, kW \cdot h$$

$$Q_{sol.W.west.02} := \phi_{sol.W.west.02} = 1.441 \times 10^{7} \, J$$

$$\phi_{sol.W.west.03} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.03} - F_{r.k} \cdot \phi_{r.W.west} = 8.85 \, kW \cdot h$$

$$Q_{sol.W.west.03} := \phi_{sol.W.west.03} = 3.186 \times 10^{7} \, J$$

$$\phi_{sol.W.west.04} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.04} - F_{r.k} \cdot \phi_{r.W.west} = 12.804 \, kW \cdot h$$

$$Q_{sol.W.west.04} := \phi_{sol.W.west.04} = 4.61 \times 10^{7} \, J$$

$$\phi_{sol.W.west.05} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.05} - F_{r.k} \cdot \phi_{r.W.west} = 17.33 \, kW \cdot h$$

$$Q_{sol.W.west.05} := \phi_{sol.W.west.05} = 6.239 \times 10^{7} \, J$$

$$\phi_{sol.W.west.09} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.09} - F_{r.k} \cdot \phi_{r.W.west} = 10.462 \, kW \cdot h$$

$$Q_{sol.W.west.09} := \phi_{sol.W.west.09} = 3.766 \times 10^{7} \, J$$

$$\phi_{sol.W.west.10} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.10} - F_{r.k} \cdot \phi_{r.W.west} = 6.855 \, kW \cdot h$$

$$Q_{sol.W.west.10} := \phi_{sol.W.west.10} = 2.468 \times 10^{7} \, J$$

$$\phi_{sol.W.west.11} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.11} - F_{r.k} \cdot \phi_{r.W.west} = 3.206 \, kW \cdot h$$

$$Q_{sol.W.west.11} := \phi_{sol.W.west.11} = 1.154 \times 10^{7} \, J$$

$$\phi_{sol.W.west.12} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.12} - F_{r.k} \cdot \phi_{r.W.west} = 3.248 \, kW \cdot h$$

$$Q_{sol.W.west.12} := \phi_{sol.W.west.12} = 1.169 \times 10^{7} \, J$$

Annual solar gains through the west wall in joules ($Q_{sol.W.west}$) and in kilowatt-hours ($\phi_{sol.W.west}$):

$$\begin{aligned} Q_{sol.W.west} := {} & Q_{sol.W.west.01} + Q_{sol.W.west.02} + Q_{sol.W.west.03} + Q_{sol.W.west.04} \cdots = 2.527 \times 10^{8} \, J \\ & + Q_{sol.W.west.05} + Q_{sol.W.west.09} + Q_{sol.W.west.10} \cdots \\ & + Q_{sol.W.west.11} + Q_{sol.W.west.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.W.west} := {} & \phi_{sol.W.west.01} + \phi_{sol.W.west.02} + \phi_{sol.W.west.03} + \phi_{sol.W.west.04} \cdots = 70.202 \, kW \cdot h \\ & + \phi_{sol.W.west.05} + \phi_{sol.W.west.09} + \phi_{sol.W.west.10} \cdots \\ & + \phi_{sol.W.west.11} + \phi_{sol.W.west.12} \end{aligned}$$

3. Solar heat gains through the north exterior wall

Effective solar collecting area of the north wall ($A_{sol.W.north}$):

$$A_{W.north} := 37.08m^2 \ldots + (1 \cdot A_{window.4} + 2 \cdot A_{window.3} + A_{door.2}) = 42.97m^2$$

$$A_{sol.W.north} := \alpha_{s.c} \cdot R_{se} \cdot U_{exterior.wall} \cdot A_{W.north} = 0.171m^2$$

Solar irradiance on the north wall for each month ($I_{sol.n.i}$):

The same as for north-oriented windows

Heat flow due to thermal radiation to the sky from the north wall ($\phi_{r.W.north}$):

$$\phi_{r.W.north} := R_{se} \cdot U_{exterior.wall} \cdot A_{W.north} \cdot h_{r.wall} \cdot \Delta\theta_{er} \cdot h = 12.081 \cdot W \cdot h$$

Solar gains through the north wall for each month ($Q_{sol.W.north.i}$):

$$\phi_{sol.W.north.01} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.01} - F_{r.k} \cdot \phi_{r.W.north} = 3.305\,kW \cdot h$$

$$Q_{sol.W.north.01} := \phi_{sol.W.north.01} = 1.19 \times 10^7\,J$$

$$\phi_{sol.W.north.02} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.02} - F_{r.k} \cdot \phi_{r.W.north} = 3.669\,kW \cdot h$$

$$Q_{sol.W.north.02} := \phi_{sol.W.north.02} = 1.321 \times 10^7\,J$$

$$\phi_{sol.W.north.03} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.03} - F_{r.k} \cdot \phi_{r.W.north} = 8.007 \cdot kW \cdot h$$

$$Q_{sol.W.north.03} := \phi_{sol.W.north.03} = 2.882 \times 10^7\,J$$

$$\phi_{sol.W.north.04} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.04} - F_{r.k} \cdot \phi_{r.W.north} = 12.077 \cdot kW \cdot h$$

$$Q_{sol.W.north.04} := \phi_{sol.W.north.04} = 4.348 \times 10^7\,J$$

$$\phi_{sol.W.north.05} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.05} - F_{r.k} \cdot \phi_{r.W.north} = 14.779\,kW \cdot h$$

$$Q_{sol.W.north.05} := \phi_{sol.W.north.05} = 5.32 \times 10^7\,J$$

$$\phi_{sol.W.north.09} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.09} - F_{r.k} \cdot \phi_{r.W.north} = 9.805\,kW \cdot h$$

$$Q_{sol.W.north.09} := \phi_{sol.W.north.09} = 3.53 \times 10^7\,J$$

$$\phi_{sol.W.north.10} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.10} - F_{r.k} \cdot \phi_{r.W.north} = 6.091 \cdot kW \cdot h$$

$$Q_{sol.W.north.10} := \phi_{sol.W.north.10} = 2.193 \times 10^{7}\,J$$

$$\phi_{sol.W.north.11} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.11} - F_{r.k} \cdot \phi_{r.W.north} = 3.18 \cdot kW \cdot h$$

$$Q_{sol.W.north.11} := \phi_{sol.W.north.11} = 1.145 \times 10^{7}\,J$$

$$\phi_{sol.W.north.12} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.12} - F_{r.k} \cdot \phi_{r.W.north} = 2.676\,kW \cdot h$$

$$Q_{sol.W.north.12} := \phi_{sol.W.north.12} = 9.633 \times 10^{6}\,J$$

Annual solar gains through the north wall in joules ($Q_{sol.W.north}$) and in kilowatt-hours ($\phi_{sol.W.north}$):

$$\begin{aligned} Q_{sol.W.north} := {} & Q_{sol.W.north.01} + Q_{sol.W.north.02} + Q_{sol.W.north.03} + Q_{sol.W.north.04} \cdots = 2.289 \times 10^{8}\,J \\ & + Q_{sol.W.north.05} + Q_{sol.W.north.09} + Q_{sol.W.north.10} \cdots \\ & + Q_{sol.W.north.11} + Q_{sol.W.north.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.W.north} := {} & \phi_{sol.W.north.01} + \phi_{sol.W.north.02} + \phi_{sol.W.north.03} + \phi_{sol.W.north.04} \cdots = 63.589\,kW \cdot h \\ & + \phi_{sol.W.north.05} + \phi_{sol.W.north.09} + \phi_{sol.W.north.10} \cdots \\ & + \phi_{sol.W.north.11} + \phi_{sol.W.north.12} \end{aligned}$$

4. Solar heat gains through the east exterior wall

Effective solar collecting area of the east wall ($A_{sol.W.east}$):

$$A_{W.east} := 45.42m^{2} + \left(1 \cdot A_{window.5} + 2 \cdot A_{window.4}\right)$$

$$A_{sol.W.east} := \alpha_{s.c} \cdot R_{se} \cdot U_{exterior.wall} \cdot A_{W.east} = 0.195m^{2}$$

Solar irradiance on the east wall for each month ($I_{sol.e.i}$):

The same as for east-oriented windows

Heat flow due to thermal radiation to the sky from the east wall ($\phi_{r.W.east}$):

$$\phi_{r.W.east} := R_{se} \cdot U_{exterior.wall} \cdot A_{W.east} \cdot h_{r.wall} \cdot \Delta\theta_{er} \cdot h = 0.014\,kW \cdot h$$

Solar gains through the east wall for each month ($Q_{sol.W.east.i}$):

$$\phi_{sol.W.east.01} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.01} - F_{r.k} \cdot \phi_{r.W.east} = 4.397 \cdot kW \cdot h$$

$$Q_{sol.W.east.01} := \phi_{sol.W.east.01} = 1.583 \times 10^{7}\,J$$

$$\phi_{sol.W.east.02} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.02} - F_{r.k} \cdot \phi_{r.W.east} = 5.093\,kW \cdot h$$

$Q_{sol.W.east.02} := \phi_{sol.W.east.02} = 1.833\times 10^{7}\ J$

$\phi_{sol.W.east.03} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.03} - F_{r.k} \cdot \phi_{r.W.east} = 12.403\, kW \cdot h$

$Q_{sol.W.east.03} := \phi_{sol.W.east.03} = 4.465\times 10^{7}\ J$

$\phi_{sol.W.east.04} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.04} - F_{r.k} \cdot \phi_{r.W.east} = 17.052\, kW \cdot h$

$Q_{sol.W.east.04} := \phi_{sol.W.east.04} = 6.139\times 10^{7}\ J$

$\phi_{sol.W.east.05} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.05} - F_{r.k} \cdot \phi_{r.W.east} = 23.499\, kW \cdot h$

$Q_{sol.W.east.05} := \phi_{sol.W.east.05} = 8.459\times 10^{7}\ J$

$\phi_{sol.W.east.09} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.09} - F_{r.k} \cdot \phi_{r.W.east} = 12.608\, kW \cdot h$

$Q_{sol.W.east.09} := \phi_{sol.W.east.09} = 4.539\times 10^{7}\ J$

$\phi_{sol.W.east.10} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.10} - F_{r.k} \cdot \phi_{r.W.east} = 8.196\, kW \cdot h$

$Q_{sol.W.east.10} := \phi_{sol.W.east.10} = 2.95\times 10^{7}\ J$

$\phi_{sol.W.east.11} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.11} - F_{r.k} \cdot \phi_{r.W.east} = 3.957\, kW \cdot h$

$Q_{sol.W.east.11} := \phi_{sol.W.east.11} = 1.424\times 10^{7}\ J$

$\phi_{sol.W.east.12} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.12} - F_{r.k} \cdot \phi_{r.W.east} = 3.181\, kW \cdot h$

$Q_{sol.W.east.12} := \phi_{sol.W.east.12} = 1.145\times 10^{7}\ J$

Annual solar gains through the east wall in joules ($Q_{sol.W.east}$) and in kilowatt-hours ($\phi_{sol.W.east}$):

$$\begin{aligned} Q_{sol.W.east} := {} & Q_{sol.W.east.01} + Q_{sol.W.east.02} + Q_{sol.W.east.03} + Q_{sol.W.east.04} \cdots = 3.254\times 10^{8}\ J \\ & + Q_{sol.W.east.05} + Q_{sol.W.east.09} + Q_{sol.W.east.10} \cdots \\ & + Q_{sol.W.east.11} + Q_{sol.W.east.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.W.east} := {} & \phi_{sol.W.east.01} + \phi_{sol.W.east.02} + \phi_{sol.W.east.03} + \phi_{sol.W.east.04} \cdots = 90.385\, kW \cdot h \\ & + \phi_{sol.W.east.05} + \phi_{sol.W.east.09} + \phi_{sol.W.east.10} \cdots \\ & + \phi_{sol.W.east.11} + \phi_{sol.W.east.12} \end{aligned}$$

Annex 2.11

Total solar heat gains through the opaque building envelope - roof

Effective solar collecting area of the roof ($A_{sol.r}$):

$$A_r := A_{conditioned.area} = 106.1\,m^2$$

$$A_{sol.r} := \alpha_{s.c} \cdot R_{se} \cdot U_{roof} \cdot A_r = 0.344\,m^2$$

Solar irradiance on the roof for each month ($I_{sol.r.i}$):

$$\left(I_{sol.r.01} := 27.962 \frac{kW \cdot h}{m^2}\right) \quad \left(I_{sol.r.04} := 99.324 \frac{kW \cdot h}{m^2}\right) \quad \left(I_{sol.r.10} := 51.570 \frac{kW \cdot h}{m^2}\right)$$

$$\left(I_{sol.r.02} := 31.503 \frac{kW \cdot h}{m^2}\right) \quad \left(I_{sol.r.05} := 155.522 \frac{kW \cdot h}{m^2}\right) \quad \left(I_{sol.r.11} := 22.963 \frac{kW \cdot h}{m^2}\right)$$

$$\left(I_{sol.r.03} := 73.137 \frac{kW \cdot h}{m^2}\right) \quad \left(I_{sol.r.09} := 76.655 \frac{kW \cdot h}{m^2}\right) \quad \left(I_{sol.r.12} := 17.769 \frac{kW \cdot h}{m^2}\right)$$

Heat flow due to thermal radiation to the sky from the roof ($\phi_{r.r}$):

$$\phi_{r.r} := R_{se} \cdot U_{roof} \cdot A_r \cdot h_{r.roof} \cdot \Delta\theta_{er} \cdot h = 0.017\,kW \cdot h$$

Solar gains through the roof for each month ($Q_{sol.r.i}$):

$$\phi_{sol.r.01} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.01} - F_{r.k} \cdot \phi_{r.r} = 9.593\,kW \cdot h$$

$$Q_{sol.r.01} := \phi_{sol.r.01} = 3.453 \times 10^7\,J$$

$$\phi_{sol.r.02} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.02} - F_{r.k} \cdot \phi_{r.r} = 10.81\,kW \cdot h$$

$$Q_{sol.r.02} := \phi_{sol.r.02} = 3.892 \times 10^7\,J$$

$$\phi_{sol.r.03} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.03} - F_{r.k} \cdot \phi_{r.r} = 25.118\,kW \cdot h$$

$$Q_{sol.r.03} := \phi_{sol.r.03} = 9.043 \times 10^7\,J$$

$$\phi_{sol.r.04} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.04} - F_{r.k} \cdot \phi_{r.r} = 34.118\,kW \cdot h$$

$$Q_{sol.r.04} := \phi_{sol.r.04} = 1.228 \times 10^8\,J$$

$$\phi_{sol.r.05} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.05} - F_{r.k} \cdot \phi_{r.r} = 53.431\,kW \cdot h$$

$$Q_{sol.r.05} := \phi_{sol.r.05} = 1.924 \times 10^8\,J$$

$$\phi_{sol.r.09} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.09} - F_{r.k} \cdot \phi_{r.r} = 26.327 \, kW \cdot h$$

$$Q_{sol.r.09} := \phi_{sol.r.09} = 9.478 \times 10^{7} \, J$$

$$\phi_{sol.r.10} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.10} - F_{r.k} \cdot \phi_{r.r} = 17.706 \, kW \cdot h$$

$$Q_{sol.r.10} := \phi_{sol.r.10} = 6.374 \times 10^{7} \, J$$

$$\phi_{sol.r.11} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.11} - F_{r.k} \cdot \phi_{r.r} = 7.875 \, kW \cdot h$$

$$Q_{sol.r.11} := \phi_{sol.r.11} = 2.835 \times 10^{7} \, J$$

$$\phi_{sol.r.12} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.12} - F_{r.k} \cdot \phi_{r.r} = 6.09 \, kW \cdot h$$

$$Q_{sol.r.12} := \phi_{sol.r.12} = 2.192 \times 10^{7} \, J$$

Annual solar gains through the roof in joules ($Q_{sol.r}$) and in kilowatt-hours ($\phi_{sol.r}$):

$$Q_{sol.r} := Q_{sol.r.01} + Q_{sol.r.02} + Q_{sol.r.03} + Q_{sol.r.04} \cdots + Q_{sol.r.05} + Q_{sol.r.09} + Q_{sol.r.10} \cdots + Q_{sol.r.11} + Q_{sol.r.12} = 6.878 \times 10^{8} \, J$$

$$\phi_{sol.r} := \phi_{sol.r.01} + \phi_{sol.r.02} + \phi_{sol.r.03} + \phi_{sol.r.04} \cdots + \phi_{sol.r.05} + \phi_{sol.r.09} + \phi_{sol.r.10} \cdots + \phi_{sol.r.11} + \phi_{sol.r.12} = 191.068 \, kW \cdot h$$

Annex 2.12

Solar heat gains through the opaque building envelope - walls + roof

Monthly solar heat gains through the opaque building envelope - walls + roof ($Q_{sol.W.r.i}$):

$$Q_{sol.W.r.01} := Q_{sol.W.south.01} + Q_{sol.W.west.01} + Q_{sol.W.north.01} + Q_{sol.W.east.01} + Q_{sol.r.01} = 8.519\times 10^{7}\ J$$

$$Q_{sol.W.r.02} := Q_{sol.W.south.02} + Q_{sol.W.west.02} + Q_{sol.W.north.02} + Q_{sol.W.east.02} + Q_{sol.r.02} = 9.471\times 10^{7}\ J$$

$$Q_{sol.W.r.03} := Q_{sol.W.south.03} + Q_{sol.W.west.03} + Q_{sol.W.north.03} + Q_{sol.W.east.03} + Q_{sol.r.03} = 2.153\times 10^{8}\ J$$

$$Q_{sol.W.r.04} := Q_{sol.W.south.04} + Q_{sol.W.west.04} + Q_{sol.W.north.04} + Q_{sol.W.east.04} + Q_{sol.r.04} = 2.949\times 10^{8}\ J$$

$$Q_{sol.W.r.05} := Q_{sol.W.south.05} + Q_{sol.W.west.05} + Q_{sol.W.north.05} + Q_{sol.W.east.05} + Q_{sol.r.05} = 4.193\times 10^{8}\ J$$

$$Q_{sol.W.r.09} := Q_{sol.W.south.09} + Q_{sol.W.west.09} + Q_{sol.W.north.09} + Q_{sol.W.east.09} + Q_{sol.r.09} = 2.309\times 10^{8}\ J$$

$$Q_{sol.W.r.10} := Q_{sol.W.south.10} + Q_{sol.W.west.10} + Q_{sol.W.north.10} + Q_{sol.W.east.10} + Q_{sol.r.10} = 1.545\times 10^{8}\ J$$

$$Q_{sol.W.r.11} := Q_{sol.W.south.11} + Q_{sol.W.west.11} + Q_{sol.W.north.11} + Q_{sol.W.east.11} + Q_{sol.r.11} = 7.243\times 10^{7}\ J$$

$$Q_{sol.W.r.12} := Q_{sol.W.south.12} + Q_{sol.W.west.12} + Q_{sol.W.north.12} + Q_{sol.W.east.12} + Q_{sol.r.12} = 5.993\times 10^{7}\ J$$

Annual solar heat gains through the opaque building envelope in joules ($Q_{sol.W.r.TOTAL.joules}$) in kilowatt-hours ($Q_{sol.W.r.TOTAL.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{sol.W.r.TOTAL.kWh.m2}$):

$$\begin{aligned} Q_{sol.W.r.TOTAL.joules} := {} & Q_{sol.W.r.01} + Q_{sol.W.r.02} + Q_{sol.W.r.03} + Q_{sol.W.r.04} \cdots = 1.627\times 10^{9}\ J \\ & + Q_{sol.W.r.05} + Q_{sol.W.r.09} + Q_{sol.W.r.10} \cdots \\ & + Q_{sol.W.r.11} + Q_{sol.W.r.12} \end{aligned}$$

$$Q_{sol.W.TOTAL.kWh} := Q_{sol.W.r.TOTAL.joules} = 451.965\ kW\cdot h$$

$$Q_{sol.W.TOTAL.kWh.m2} := \frac{Q_{sol.W.r.TOTAL.joules}}{A_{conditioned.area}} = 4.26\ \frac{kW\cdot h}{m^2}$$

Annex 2.13

Total heat gains

Monthly heat gains ($Q_{gn.i}$):

$$Q_{gn.01} := Q_{.int.01} + Q_{sol.w.01} + Q_{sol.W.r.01} = 4.354 \times 10^{9}\,J$$

$$Q_{gn.02} := Q_{.int.02} + Q_{sol.w.02} + Q_{sol.W.r.02} = 4.033 \times 10^{9}\,J$$

$$Q_{gn.03} := Q_{.int.03} + Q_{sol.w.03} + Q_{sol.W.r.03} = 5.236 \times 10^{9}\,J$$

$$Q_{gn.04} := Q_{.int.04} + Q_{sol.w.04} + Q_{sol.W.r.04} = 5.201 \times 10^{9}\,J$$

$$Q_{gn.05} := Q_{.int.05} + Q_{sol.w.05} + Q_{sol.W.r.05} = 6.179 \times 10^{9}\,J$$

$$Q_{gn.09} := Q_{.int.09} + Q_{sol.w.09} + Q_{sol.W.r.09} = 4.654 \times 10^{9}\,J$$

$$Q_{gn.10} := Q_{.int.10} + Q_{sol.w.10} + Q_{sol.W.r.10} = 4.57 \times 10^{9}\,J$$

$$Q_{gn.11} := Q_{.int.11} + Q_{sol.w.11} + Q_{sol.W.r.11} = 3.469 \times 10^{9}\,J$$

$$Q_{gn.12} := Q_{.int.12} + Q_{sol.w.12} + Q_{sol.W.r.12} = 3.797 \times 10^{9}\,J$$

Annual total heat gains in joules ($Q_{gn.joules}$) in kilowatt-hours ($Q_{gn.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{gn.kWh.m2}$):

$$Q_{gn.joules} := Q_{gn.01} + Q_{gn.02} + Q_{gn.03} + Q_{gn.04} + Q_{gn.05} + Q_{gn.09} + Q_{gn.10} + Q_{gn.11} + Q_{gn.12} = 4.149 \times 10^{10}\,J$$

$$Q_{gn.kWh} := Q_{gn.joules} = 1.153 \times 10^{4} \cdot kW \cdot h$$

$$Q_{gn.kWh.m2} := \frac{Q_{gn.joules}}{A_{conditioned.area}} = 108.633 \frac{kW \cdot h}{m^2}$$

Annex 2.14

Dynamic parameters

Heat-balance ratio for each month ($\gamma_{H.i}$):

$$\gamma_{H.01} := \frac{Q_{gn.01}}{Q_{ht.01}} = 0.847 \qquad \gamma_{H.04} := \frac{Q_{gn.04}}{Q_{ht.04}} = 1.827 \qquad \gamma_{H.10} := \frac{Q_{gn.10}}{Q_{ht.10}} = 1.714$$

$$\gamma_{H.02} := \frac{Q_{gn.02}}{Q_{ht.02}} = 0.909 \qquad \gamma_{H.05} := \frac{Q_{gn.05}}{Q_{ht.05}} = 3.778 \qquad \gamma_{H.11} := \frac{Q_{gn.11}}{Q_{ht.11}} = 0.94$$

$$\gamma_{H.03} := \frac{Q_{gn.03}}{Q_{ht.03}} = 1.289 \qquad \gamma_{H.09} := \frac{Q_{gn.09}}{Q_{ht.09}} = 2.982 \qquad \gamma_{H.12} := \frac{Q_{gn.12}}{Q_{ht.12}} = 0.807$$

Time constant (τ):

$$\tau := \frac{\frac{C_m}{3600}}{H_{tr.adj} + H_{ve.adj}} = 0.064h$$

Numerical parameter (a_H):

$$a_H := a_{H.0} + \frac{\tau}{\tau_{H.0}} = 1.004$$

Gain utilization factors for each month ($\eta_{H.gn.i}$):

$$\eta_{H.gn.01} := \frac{1 - \gamma_{H.01}^{a_H}}{1 - \gamma_{H.01}^{a_H+1}} = 0.542 \qquad \eta_{H.gn.09} := \frac{a_H}{a_H + 1} = 0.501$$

$$\eta_{H.gn.02} := \frac{1 - \gamma_{H.02}^{a_H}}{1 - \gamma_{H.02}^{a_H+1}} = 0.525 \qquad \eta_{H.gn.10} := \frac{1 - \gamma_{H.10}^{a_H}}{1 - \gamma_{H.10}^{a_H+1}} = 0.369$$

$$\eta_{H.gn.03} := \frac{1 - \gamma_{H.03}^{a_H}}{1 - \gamma_{H.03}^{a_H+1}} = 0.438 \qquad \eta_{H.gn.11} := \frac{1 - \gamma_{H.11}^{a_H}}{1 - \gamma_{H.11}^{a_H+1}} = 0.516$$

$$\eta_{H.gn.04} := \frac{1 - \gamma_{H.04}^{a_H}}{1 - \gamma_{H.04}^{a_H+1}} = 0.354 \qquad \eta_{H.gn.12} := \frac{1 - \gamma_{H.12}^{a_H}}{1 - \gamma_{H.12}^{a_H+1}} = 0.555$$

$$\eta_{H.gn.05} := \frac{a_H}{a_H + 1} = 0.501$$

Annex 15

Total energy need for heating

Energy need for heating for each month ($Q_{H.nd.i}$):

$$Q_{H.nd.01} := Q_{ht.01} - \eta_{H.gn.01} \cdot Q_{gn.01} = 2.777 \times 10^{9}\,J$$

$$Q_{H.nd.02} := Q_{ht.02} - \eta_{H.gn.02} \cdot Q_{gn.02} = 2.318 \times 10^{9}\,J$$

$$Q_{H.nd.03} := Q_{ht.03} - \eta_{H.gn.03} \cdot Q_{gn.03} = 1.77 \times 10^{9}\,J$$

$$Q_{H.nd.04} := Q_{ht.04} - \eta_{H.gn.04} \cdot Q_{gn.04} = 1.003 \times 10^{9}\,J$$

$$Q_{H.nd.05} := Q_{ht.05} - \eta_{H.gn.05} \cdot Q_{gn.05} = -1.461 \times 10^{9}\,J$$

$$Q_{H.nd.09} := Q_{ht.09} - \eta_{H.gn.09} \cdot Q_{gn.09} = -7.712 \times 10^{8}\,J$$

$$Q_{H.nd.10} := Q_{ht.10} - \eta_{H.gn.10} \cdot Q_{gn.10} = 9.789 \times 10^{8}\,J$$

$$Q_{H.nd.11} := Q_{ht.11} - \eta_{H.gn.11} \cdot Q_{gn.11} = 1.897 \times 10^{9}\,J$$

$$Q_{H.nd.12} := Q_{ht.12} - \eta_{H.gn.12} \cdot Q_{gn.12} = 2.599 \times 10^{9}\,J$$

Annual total energy need for heating in joules ($Q_{H.nd.joules}$) in kilowatt-hours ($Q_{H.nd.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{H.nd.kWh.m2}$):

$$\begin{aligned} Q_{H.nd.joules} := {} & Q_{H.nd.01} + Q_{H.nd.02} + Q_{H.nd.03} + Q_{H.nd.04} \cdots = 1.257 \times 10^{10}\,J \\ & + Q_{H.nd.05} + Q_{H.nd.09} + Q_{H.nd.10} \cdots \\ & + Q_{H.nd.11} + Q_{H.nd.12} \end{aligned}$$

$$Q_{H.nd.joules.kWh} := Q_{H.nd.joules} = 3.492 \times 10^{3} \cdot kW \cdot h$$

Requirement:

$$Q_{H.nd.kWh.m2} := \frac{Q_{H.nd.joules}}{A_{conditioned.area}} = 32.915 \frac{kW \cdot h}{m^2}$$

$$E_{0.conditioned.area} := 124.72 kW \cdot \frac{h}{m^3}$$

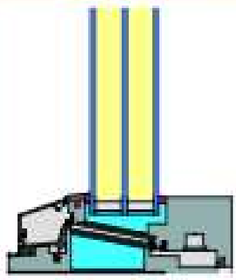
Annex 3.1: Window frame

Certificate

Certified Passive House Component
for cold climates; valid until 31.12.2014

Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
GERMANY

Category:	**Window Frame**
Manufacturer:	**pro Passivhausfenster**
	83080 Oberaudorf, GERMANY
Product name:	**smartwin arctic**



Passive House Efficiency Class

phA+ very adv. component

phA advanced component

phB basic component

phC certifiable component

not suitable for Passive Houses

This certificate was awarded based on the following criteria:

Given a Ug value of 0.520 W/(m²K) and a window size of 1.23 m by 1.48 m,

U_W = 0.60 W/(m²K) ≤ 0.60 W/(m²K)

Taking into account the installation based thermal bridges and provided that the installation is, with regard to the thermal bridges, equal or better than shown in the data sheet, the window meets the following criterion.

$U_{W,installed}$ ≤ 0.65 W/(m²K)

Thermal data

	U_f-value [W/(m²K)]	Width [mm]	Ψ_g [W/(mK)]	$f_{Rsi=0.25}$ [-]
Spacer			SWISSP. Ultimate PU*	
Bottom	0.72	58	0.021	0.76
Side/top	0.64	58	0.021	

*Spacers of lower thermal quality, especially those made of aluminium, lead to significantly higher thermal losses and lower temperature factors.

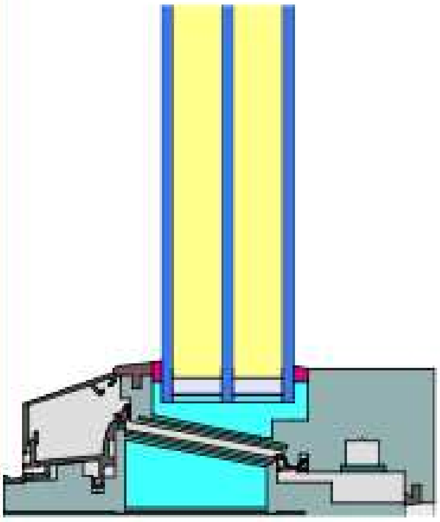
For further information, please see the data sheet

phA+ CERTIFIED COMPONENT Passive House Institute

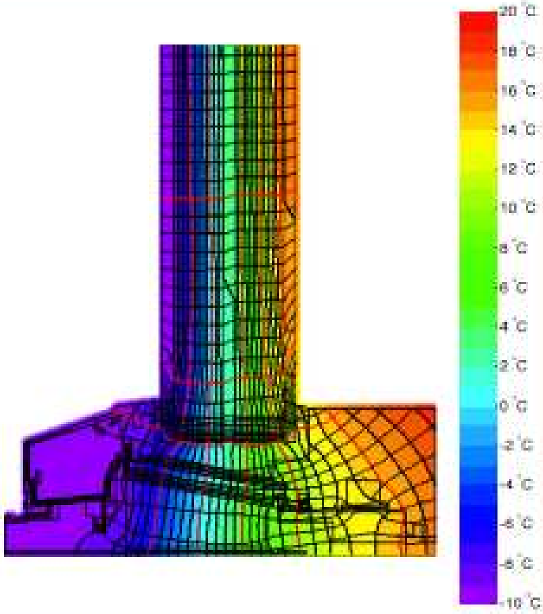
www.passivehouse.com 0632wi02

Data Sheet pro Passivhausfenster, smartwin arctic

Manufacturer pro Passivhausfenster
Martin-Greif-Straße 20, 83080 Oberaudorf, GERMANY
Tel.: +49 8033304098
Email: phc@freundorfer.eu, www.propassivhausfenster.net



Bottom section



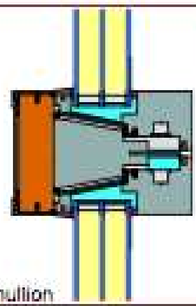
Isothermal

Description

Alluminum cladded timber frame (Spruce/Fir, 0.11 W/(mK)), insulated by low dense timber-faser board (0,05 W/(mK)) & PU insulation (0,027 W/(mK)). Glazing: 4/18/4/18/4. Glass intersection: 15 mm. Spacer: SWISSPACER Ultimate with PU secondary seal.. Pane thickness: 48 mm (4/18/4/18/4), Rebate depth: 15 mm.

Thermal data for the window frame

	U_f-value [W/(m²K)]	Width [mm]	Ψ_g [W/(mK)]	$f_{Rsi=0.25}$ [-]
Spacer			SWISSP. Ultimate PU*	
Bottom	0.72	58	0.021	0.76
Side/Top	0.64	58	0.021	
Flying Mullion	0.69	110	0.021	0.77



Flying mullion

* Spacers of lower thermal quality lead to higher thermal losses and lower glass edge temperatures.

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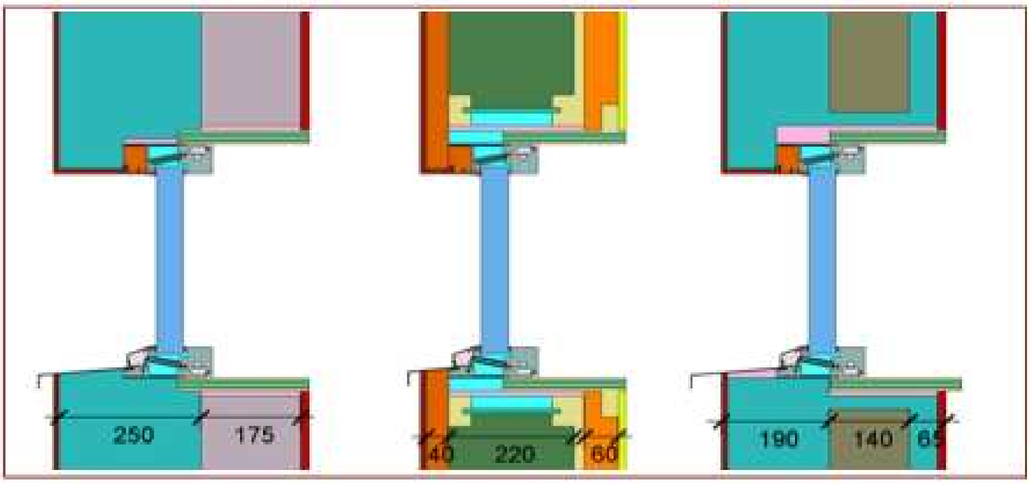
Data Sheet pro Passivhausfenster, smartwin arctic

Installation



Installation based thermal bridge $\Psi_{instal.}$ in Passive House suitable walls

Position		EIFS	Timber construction wall	Insulated formwork blocks
Bottom	[W/(mK)]	0.016	0.020	0.017
Side/Top	[W/(mK)]	0.008	0.017	0.010
$U_{W,instal.}$	[W/(m²K)]	0.63	0.65	0.64

Explanatory notes

The window U-values were calculated based on a 1.23 m by 1.48 m window U_g = 0.52 W/(m²K).
If other glazing is used, the window U-values changes as follows:

U Glazing	U_g [W/(m²K)]	0.70	0.64	0.44
U Window	U_W [W/(m²K)]	0.75	0.70	0.53

Depending on the thermal losses through opaque elements, transparent components are categorised according to efficency classes. These thermal losses include the losses through the frame, the frame width, the thermal bridge at the glass edge as well as the length of the glass edge. Certificates for arctic regions are too valid vor cold, certificates for cold regions are too valid for cool, temperate zones.
Please ask the manufacturer for a detailed report containing all calculations and results.
For further information, please visit www.passivehouse.com or www.passipedia.org.

www.passivehouse.com

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Annex 4.2: Window glazing

Certificate

Certified Passive House component

For cool temperate climates, valid until 31. December 2014

Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
GERMANY

Category **Glazing**

Manufacturer **INTERPANE GLAS INDUSTRIE AG**
D 37697 Lauenförde, Sohnreystr. 21, GERMANY

Product name: **iplus 3CE**

This certificate was awarded based on the following criteria:

Thermal Comfort

$$U_g \text{ (EN 673)} \leq 0.80 \text{ W/(m}^2\text{K)} \quad [1]$$

Explanatory statement: In Passive Houses buildings with standard room height, no heating units are needed along the outer walls. In order to avoid thermal discomfort due to radiation heat losses, glazing U-values must be limited.

Energy Balance for glazings

for cool temperate climates

$$U_g \text{ [W/m}^2\text{/K]} - 1.6 * g \leq 0 \quad [2]$$

Explanatory statement: Glazing on south facing facades with minimal shading must also provide net heat gains during the relatively short Passive House heating period (November to February).

Please note: Formula [2] is a rough estimation for this component in cool, temperate climates and thus reflects the energy balance for a very particular set of conditions. For the actual building the energy balance must be evaluated with the Passive House Planning Package (PHPP) or other suitable thermal simulation tool. The value given on the left hand side of formula [2] may not be used in place of the certified U_g-values given below.

Passive Houses Requirements

For proper function in a Passive House this glazings must be mounted into a well-insulated Passive House suitable window frame. A thermally seperated spacer must be used at the gass edge to reduce thermal bridging.

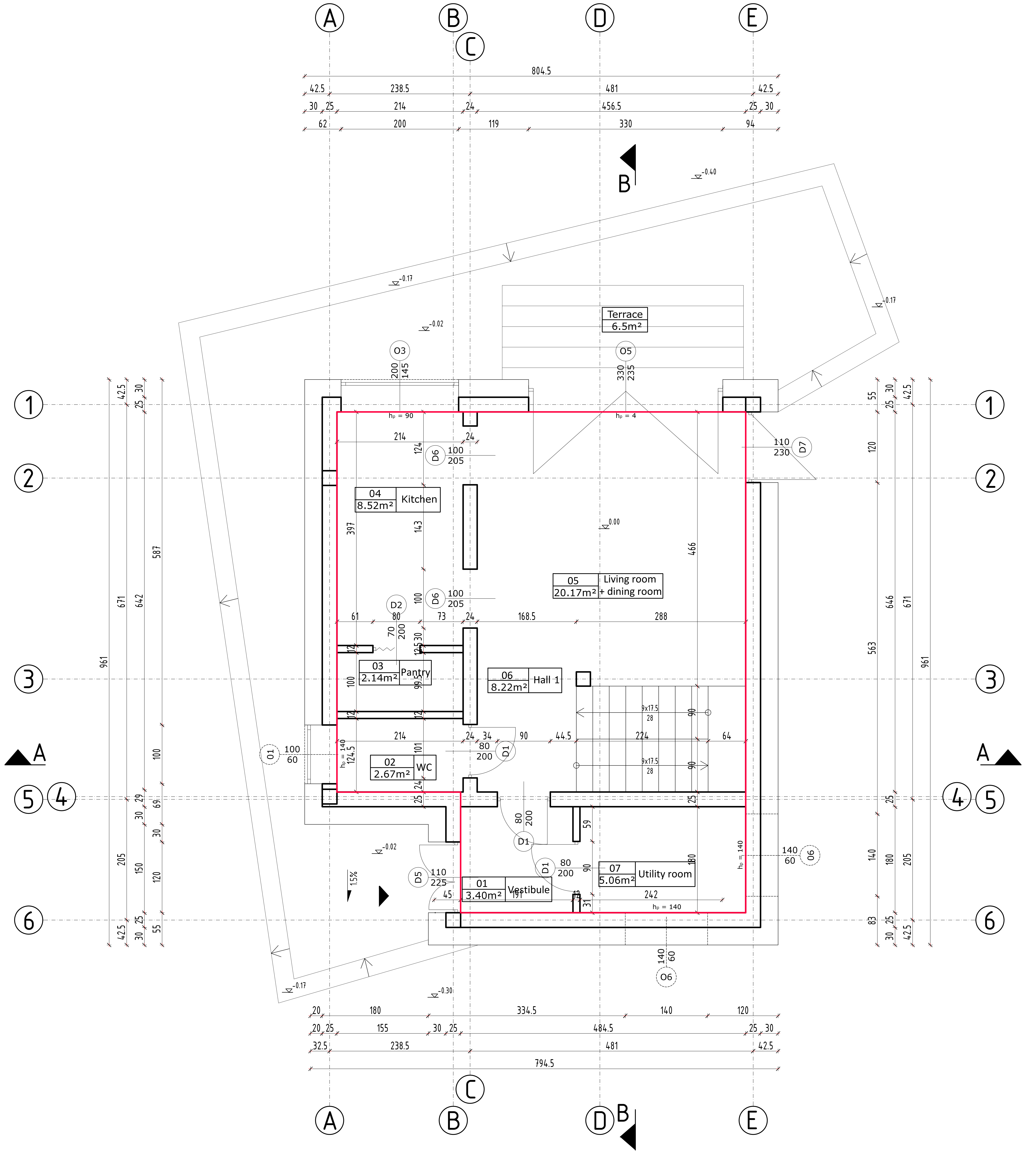
Thermal quality and solar throughput:

Glazing Profile	U_g (EN 673) [W/(m²K)]	g (EN 410) [-]
4:/12/4/12/:4 Kr 90%	0.49	0.50
4:/10/4/10/:4 Kr 90%	0.56	0.50

CERTIFIED COMPONENT
Passive House Institute

www.passivehouse.com

0415gl03 - 0416gl03



GROUND FLOOR PLAN

THERMAL ENVELOPE

N

AREAS OF COMPARTMENTS			
GROUND FLOOR			

Nr	Name of compartment	Usable area [m²]	Final covering
01	Vestibule	3.40	Gres tiles
02	WC	2.67	Gres tiles
03	Pantry	2.14	Terracotta tiles
04	Kitchen	8.52	Terracotta tiles
05	Living room + dining room	20,17	Wooden panels
06	Hall 1	8,22	Gres tiles
07	Utility room	5.06	Gres tiles
	Total	51.17	

SUBJECT: ANNEX 4.1.

GROUND FLOOR PLAN – THERMAL ENVELOPE

University of Aveiro

DRAWN BY: MARTA MOSKALIK

DRAWING NUMBER: 1

PROJECT:

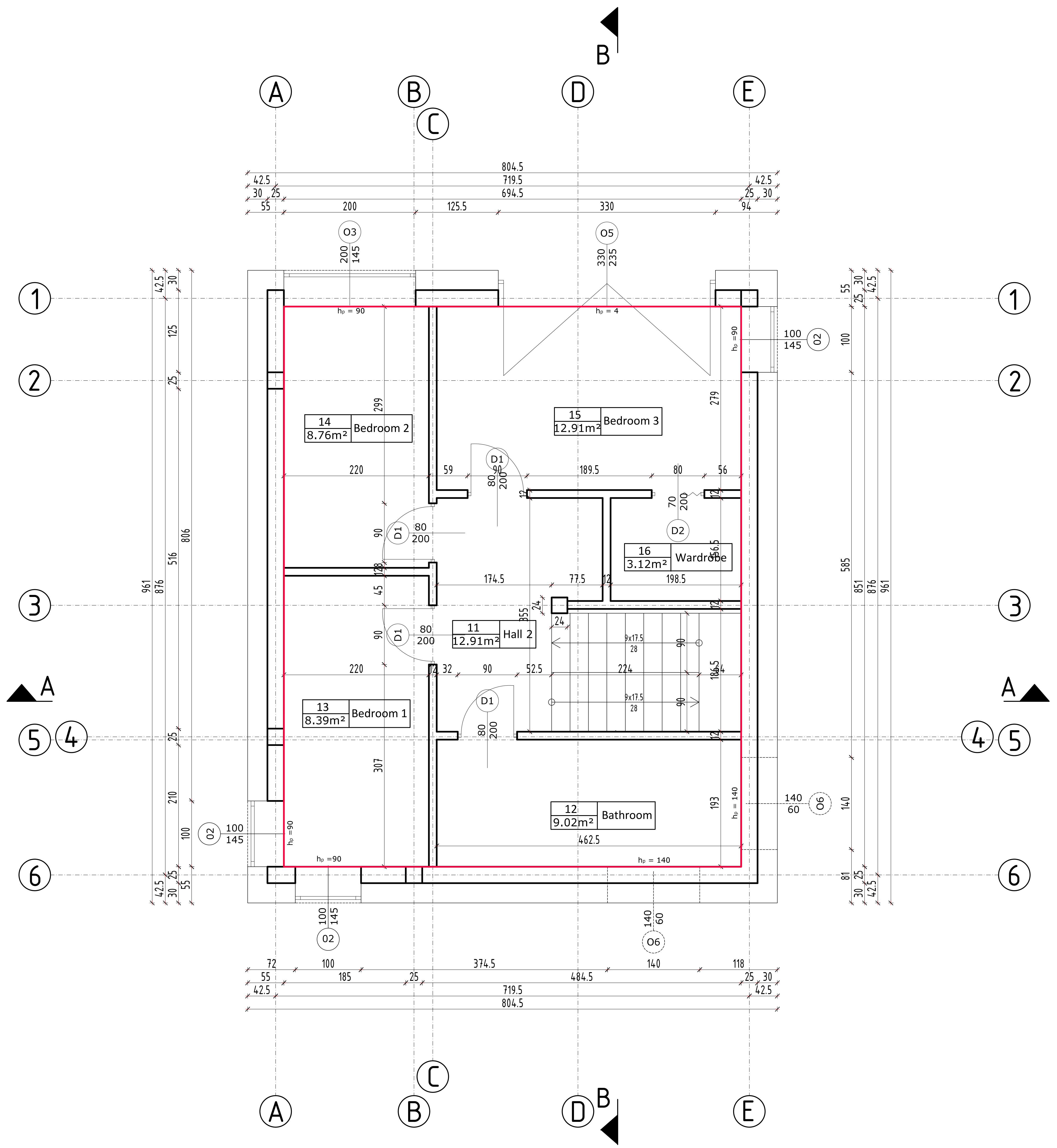
MASTER THESIS:

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

SCALE: 1:50

DATE: 1.07.2014



FIRST FLOOR PLAN

THERMAL ENVELOPE

AREAS OF COMPARTMENTS			
FIRST FLOOR			
Nr	Name of compartment	Usable area [m²]	Final covering
11	Hall 2	12.69	Gres tiles
12	Bedroom 1	8.39	Wooden panels
13	Bedroom 2	8.76	Wooden panels
14	Bathroom	9.02	Gres tiles
15	Bedroom 3	12.91	Wooden panels
16	Wardrobe	3.12	Wooden panels
	Total	54.89	

SUBJECT: ANNEX 4.2.

FIRST FLOOR PLAN – THERMAL ENVELOPE

University of Aveiro

DRAWN BY: MARTA MOSKALIK

DRAWING NUMBER: 2

PROJECT:

MASTER THESIS:

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

SCALE: 1:50

DATE: 1.07.2014

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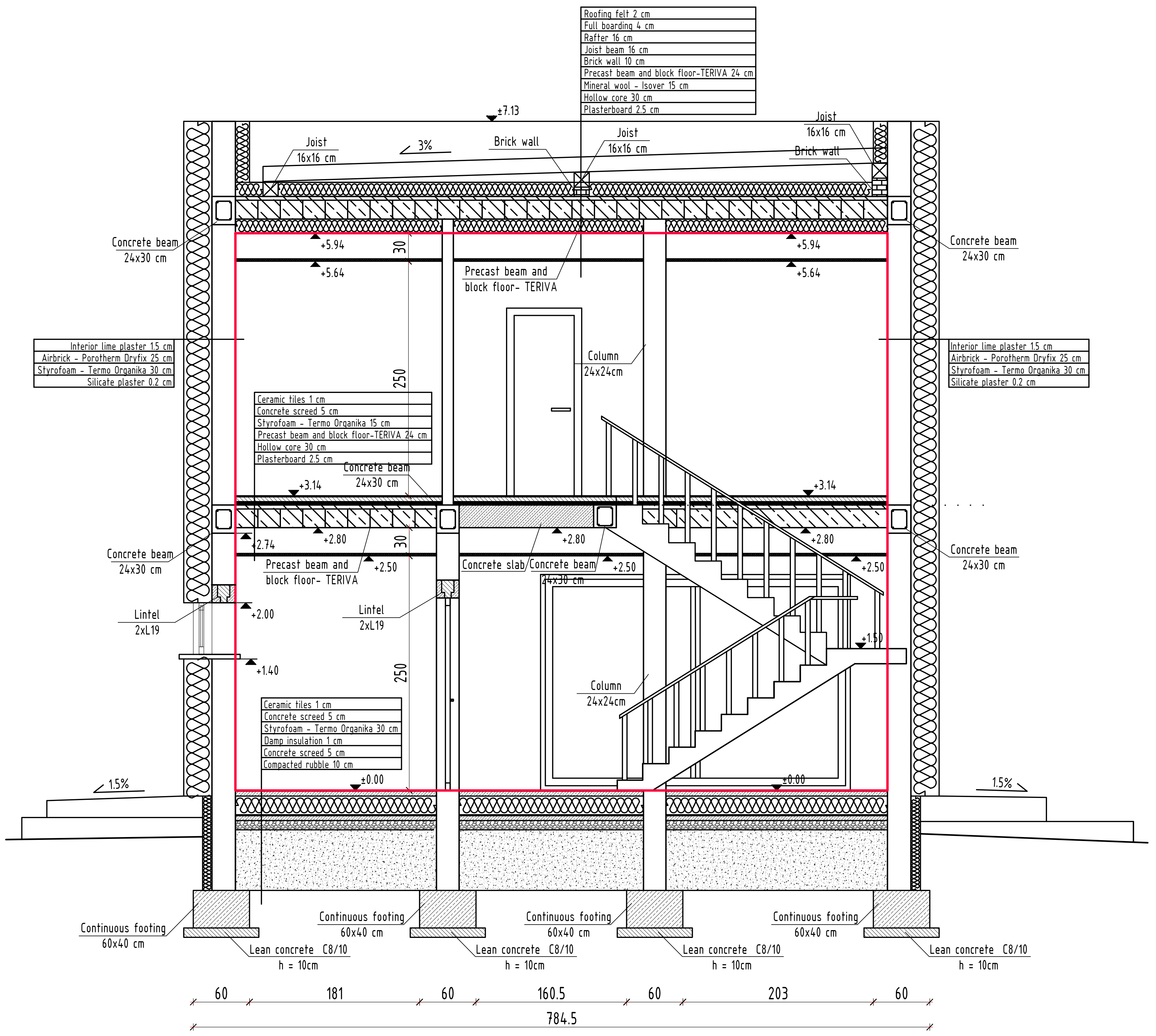


CROSS-SECTION A-A

THERMAL ENVELOPE

SUBJECT:

ANNEX 4.3.

CROSS-SECTION A-A – THERMAL ENVELOPE

University of Aveiro

DRAWN BY:

MARTA MOSKALIK

DRAWING NUMBER:

3

PROJECT:

MASTER THESIS:

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

SCALE:

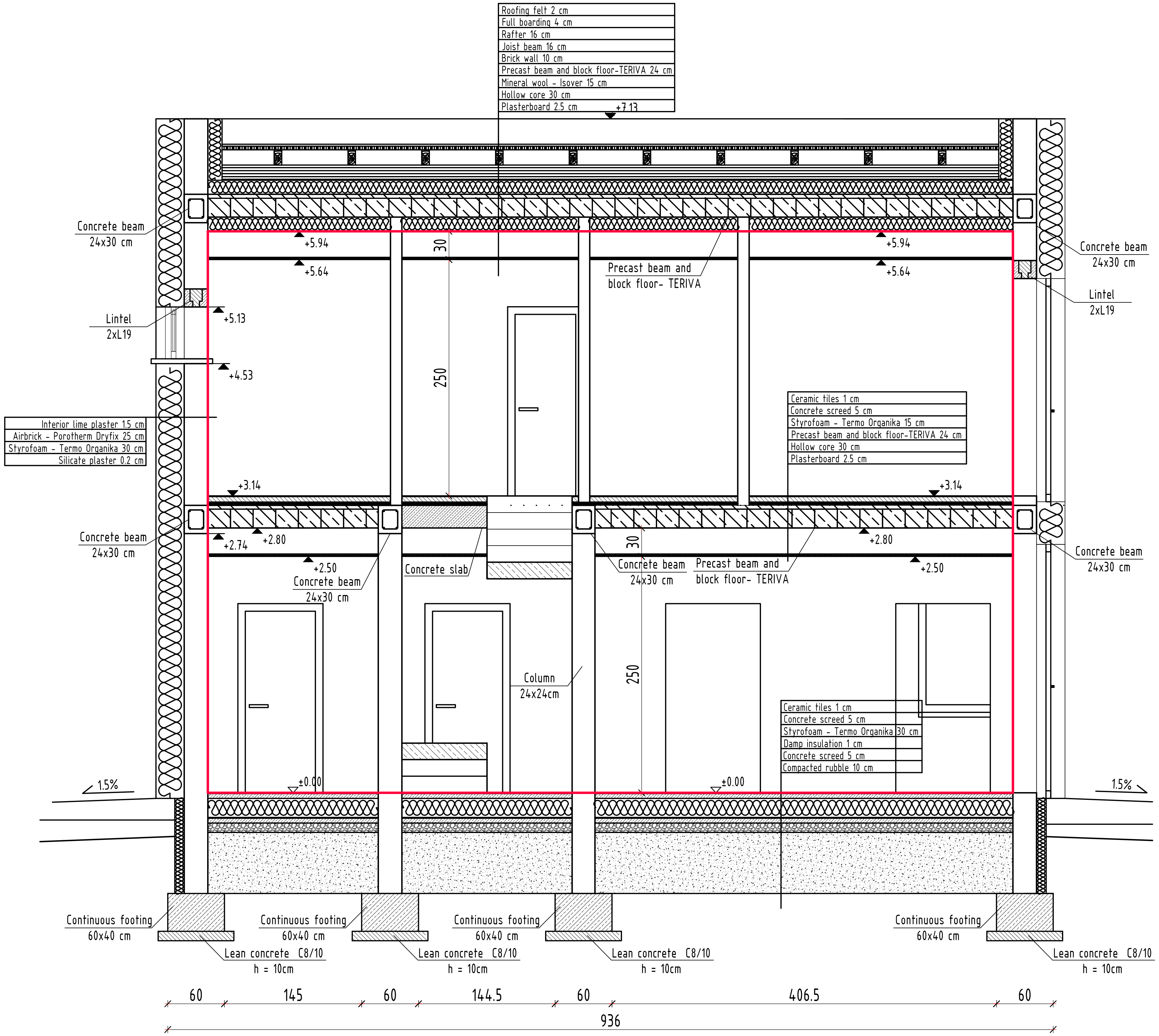
1:50

DATE:

1.07.2014

CROSS-SECTION B-B

THERMAL ENVELOPE



ANNEX 4.4.

CROSS-SECTION B-B – THERMAL ENVELOPE

University of Aveiro

MARTA MOSKALIK

DRAWING NUMBER: 4

SCALE: 1:50

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

DATE: 1.07.2014

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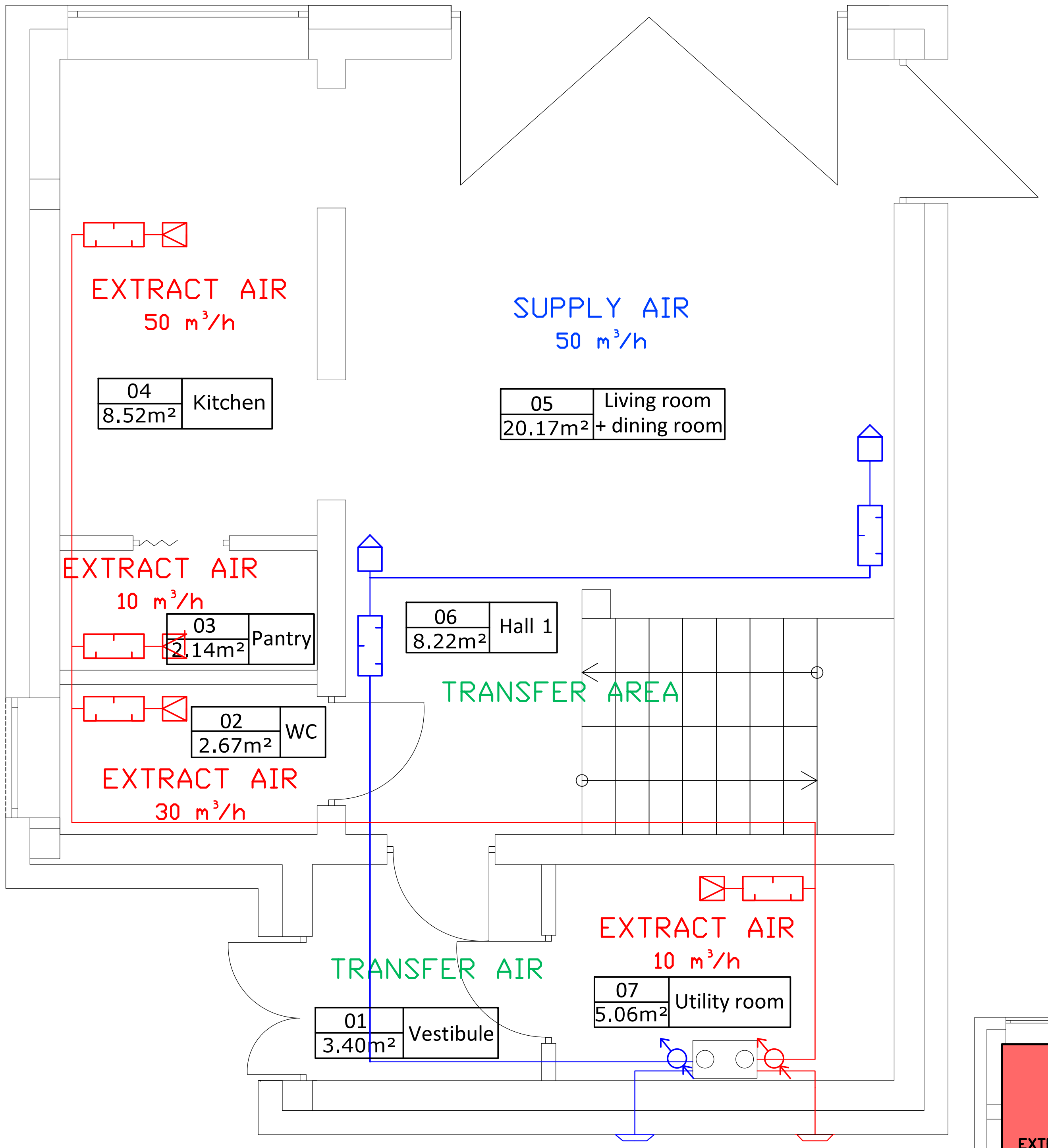
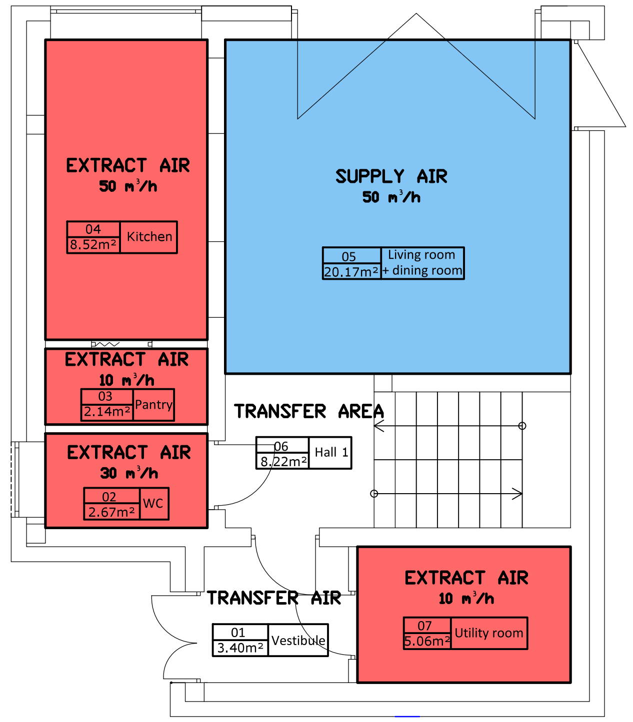
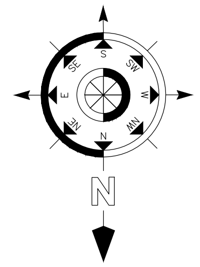




GROUND FLOOR PLAN

VENTILATION



LEGEND

- extract outlet
- supply outlet
- silencer

AREAS OF COMPARTMENTS			
GROUND FLOOR			
Nr	Name of compartment	Usable area [m²]	Final covering
01	Vestibule	3.40	Gres tiles
02	WC	2.67	Gres tiles
03	Pantry	2.14	Terracotta tiles
04	Kitchen	8.52	Terracotta tiles
05	Living room + dining room	20,17	Wooden panels
06	Hall 1	8,22	Gres tiles
07	Utility room	5.06	Gres tiles
	Total	51.17	

SUBJECT: ANNEX 4.5.

GROUND FLOOR PLAN – VENTILATION

University of Aveiro

DRAWN BY: MARTA MOSKALIK

DRAWING NUMBER: 5

PROJECT:

MASTER THESIS:

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

SCALE: 1:50

DATE: 1.07.2014

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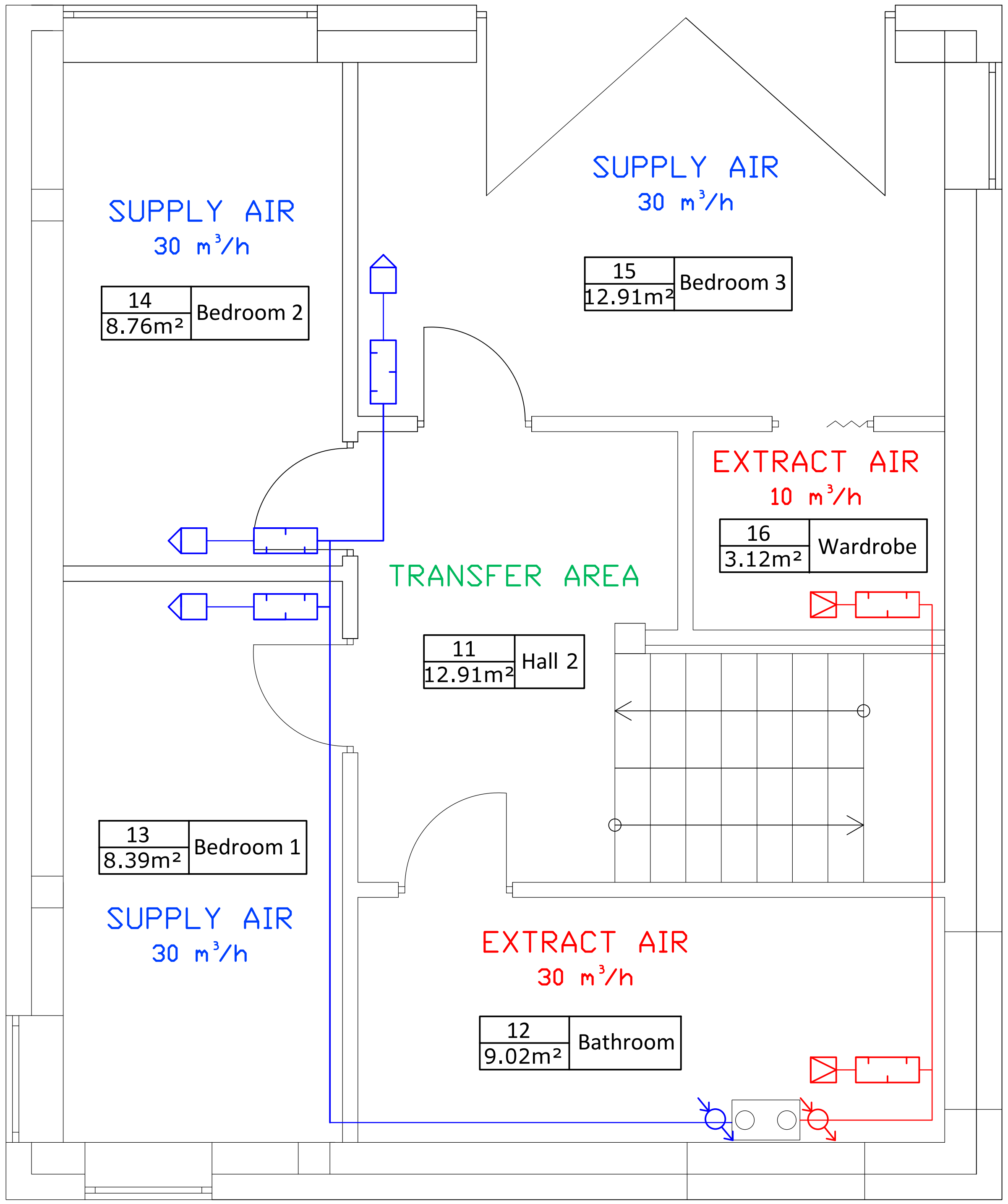
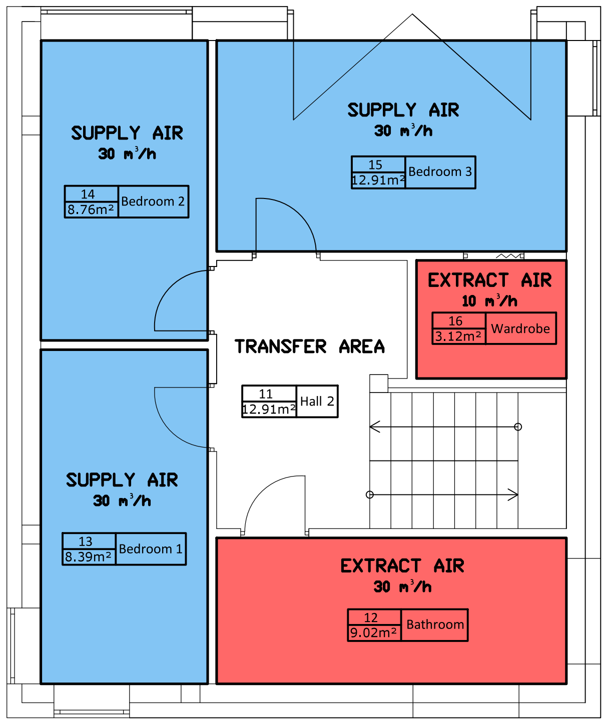
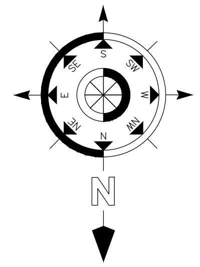




FIRST FLOOR PLAN

VENTILATION



LEGEND

extract outlet
supply outlet
silencer

AREAS OF COMPARTMENTS			
FIRST FLOOR			
Nr	Name of compartment	Usable area [m²]	Final covering
11	Hall 2	12.69	Gres tiles
12	Bedroom 1	8.39	Wooden panels
13	Bedroom 2	8.76	Wooden panels
14	Bathroom	9.02	Gres tiles
15	Bedroom 3	12.91	Wooden panels
16	Wardrobe	3.12	Wooden panels
	Total	54.89	

SUBJECT: ANNEX 4.6.

FIRST FLOOR PLAN – VENTILATION

University of Aveiro

DRAWN BY: MARTA MOSKALIK

DRAWING NUMBER: 6

PROJECT:

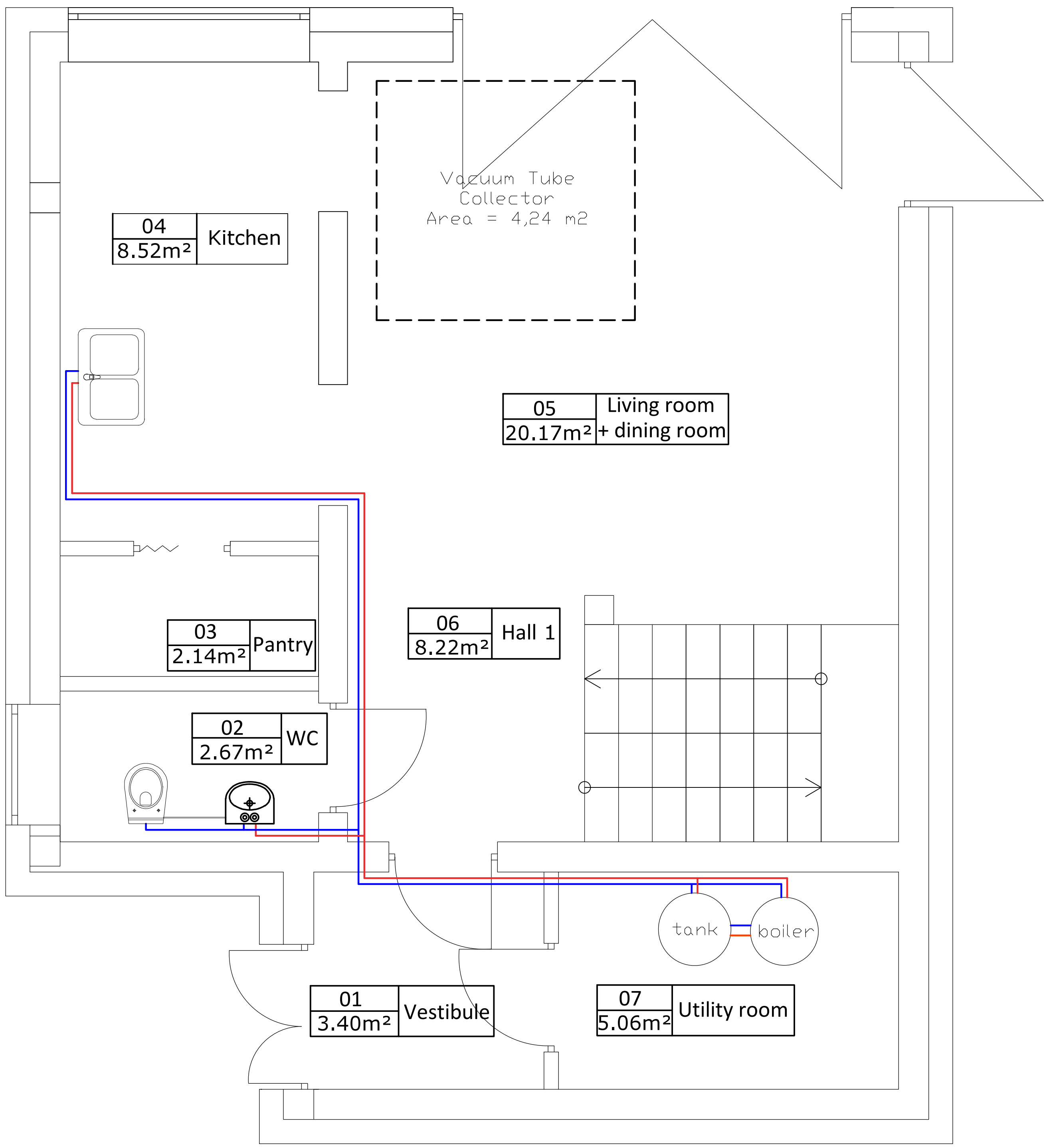
MASTER THESIS:

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

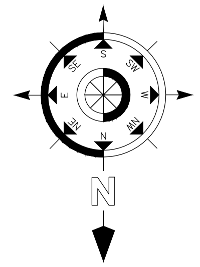
SCALE: 1:50

DATE: 1.07.2014



GROUND FLOOR PLAN

DOMESTIC HOT WATER



LEGEND

hot water pipe

cold water pipe

greywater pipe

AREAS OF COMPARTMENTS			
GROUND FLOOR			
Nr	Name of compartment	Usable area [m²]	Final covering
01	Vestibule	3.40	Gres tiles
02	WC	2.67	Gres tiles
03	Pantry	2.14	Terracotta tiles
04	Kitchen	8.52	Terracotta tiles
05	Living room + dining room	20,17	Wooden panels
06	Hall 1	8,22	Gres tiles
07	Utility room	5.06	Gres tiles
	Total	51.17	

SUBJECT: ANNEX 4.7.

GROUND FLOOR PLAN – DOMESTIC HOT WATER

University of Aveiro

DRAWN BY: MARTA MOSKALIK

DRAWING NUMBER: 7

PROJECT:

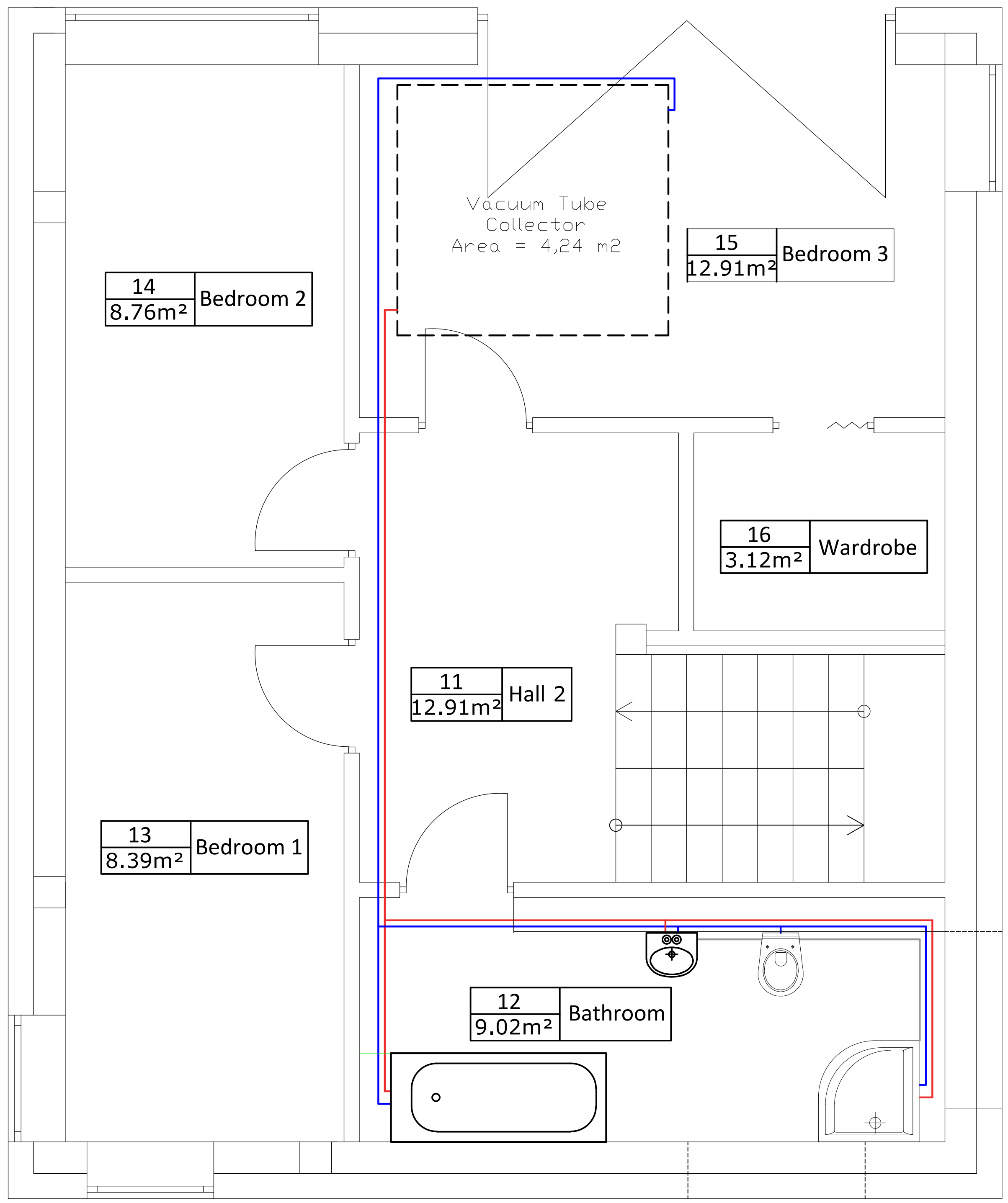
MASTER THESIS:

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

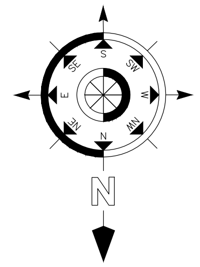
SCALE: 1:50

DATE: 1.07.2014



FIRST FLOOR PLAN

DOMESTIC HOT WATER



LEGEND

hot water pipe

cold water pipe

greywater pipe

AREAS OF COMPARTMENTS			
FIRST FLOOR			
Nr	Name of compartment	Usable area [m²]	Final covering
11	Hall 2	12.69	Gres tiles
12	Bedroom 1	8.39	Wooden panels
13	Bedroom 2	8.76	Wooden panels
14	Bathroom	9.02	Gres tiles
15	Bedroom 3	12.91	Wooden panels
16	Wardrobe	3.12	Wooden panels
	Total	54.89	

SUBJECT: ANNEX 4.8.

FIRST FLOOR PLAN – DOMESTIC HOT WATER

University of Aveiro

DRAWN BY: MARTA MOSKALIK

DRAWING NUMBER: 8

PROJECT:

MASTER THESIS:

PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE

PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO

SCALE: 1:50

DATE: 1.07.2014

ELEVATIONS

SUBJECT:	ANNEX 4.9. ELEVATIONS University of Aveiro	
DRAWN BY: MARTA MOSKALIK		DRAWING NUMBER: 9
PROJECT: MASTER THESIS: PASSIVE HOUSE APPLICATION FOR POLISH CLIMATE PASSIVE HOUSE APLICAÇÃO PARA O CLIMA POLACO		SCALE: 1:100
		DATE: 1.07.2014